INSTITUTO UNIVERSITÁRIO DE LISBOA

Digitalization in Healthcare: Innovation Diffusion and Maturity Study in Pediatric Departments of Six Hospitals in the Pearl River Delta

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Doctor of Management

Supervisors:
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Florida International University

March, 2025

BUSINESS
SCHOOL

Marketing, Operations and General Management Department

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Abstract

A large number of government documents require hospitals to undergo digital transformation, but existing research lacks a systematic explanation of its internal mechanisms. Focusing on pediatrics in six hospitals in the Pearl River Delta, this study aims to decipher the differentiation logic of different institutions in technology adoption, resource allocation, etc., providing theoretical support for optimizing regional medical digitization.

The research integrates innovation diffusion, institutional theory, and complex adaptive systems theory, collects qualitative data through in-depth interviews, refines core categories using three-level coding, and analyzes the configurational effects of multiple factors with fsQCA. A "dynamic balance model" is constructed, focusing on five antecedent variables including leadership-operation, regional economy, and user characteristics, to analysis the interaction mechanism between macro policies and micro operations.

The study shows that differences in pediatric digital maturity result from the dynamic interaction of multiple factors: public hospitals rely on top-down promotion, with regional economy and policies influencing resource allocation; young parents' high digital literacy reduces technical barriers, while organizational cultural differences lead to disciplinary path differentiation; private hospitals build trust through personalized services, and small hospitals depend on government funding. The "dynamic balance model" identifies an "adaptive threshold," emphasizing that technology investment must match organizational readiness to avoid system friction.

Theoretically, this study integrates multiple theories, reveals the collaborative mechanism of institutional pressure, innovation diffusion, and system adaptability, and improves the digital maturity evaluation framework. Practically, it provides policymakers with regional resource optimization indicators, helps hospital managers design differentiated digital roadmaps, and promotes the transformation of pediatric care toward efficiency, precision, and personalization.

Keywords: Pediatric Hospital; Digital Maturity; Dynamic Balance Model

JEL: I12; M15

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Resumo

Um grande número de diretivas governamentais exigem que os hospitais se transformem digitalmente, mas as pesquisas existentes carecem de uma explicação sistemática dos seus mecanismos internos. Este estudo, focalizado no serviço de pediatria de seis hospitais da região do Delta do Rio das Pérolas,na China, visa compreender a lógica de diferenciação entre as instituições, em relação à adoção de tecnologia, alocação de recursos, etc., fornecendo suporte teórico para a otimização da digitalização médica regional.

A pesquisa integra a *Teoria da Difusão da Inovação, a Teoria Institucional e a Teoria dos Sistemas Complexos Adaptativos*. Os dados qualitativos são recolhidos através de entrevistas em profundidade, sendo as categorias centrais refinadas por meio de codificação em três níveis. Os efeitos configuracionais de múltiplos fatores são analisados com recurso à *Análise Comparativa Qualitativa Fuzzy-Set* (fsQCA). É construído um “modelo de equilíbrio dinâmico”, centrado em cinco variáveis antecedentes - incluindo liderança-operação, economia regional e características dos utilizadores - para analisar os mecanismos de interação entre as políticas macro e as operações micro.

O estudo mostra que as diferenças na maturidade digital na pediatria resultam da interação dinâmica de múltiplos fatores: os hospitais públicos dependem de impulsos hierárquicos, sendo que a economia regional e as políticas influenciam a alocação de recursos; a alta alfabetização digital dos pais jovens reduz as barreiras tecnológicas, enquanto as diferenças de cultura organizacional levam a diferenciações de caminhos disciplinares; hospitais privados constroem confiança por meio de serviços personalizados, e hospitais pequenos dependem de recursos governamentais. O "Modelo de Equilíbrio Dinâmico" identifica um "limiar adaptativo", enfatizando que o investimento em tecnologia deve ser compatível com a prontidão organizacional para evitar conflitos sistémicos.

Do ponto de vista teórico, este estudo integra múltiplas teorias, revela o mecanismo colaborativo entre a pressão institucional, a difusão da inovação e a adaptabilidade dos sistemas, e aprimora o quadro de avaliação da maturidade digital. Em termos práticos, fornece aos decisores políticos indicadores para a otimização de recursos regionais, auxilia os gestores hospitalares na conceção de roteiros digitais diferenciados e promove a transformação dos cuidados pediátricos no sentido da eficiência, precisão e personalização.

Palavras-chave: Hospital Pediátrico; Maturidade Digital; Modelo de Equilíbrio Dinâmico
JEL: I12; M15

摘　要

大量政府文件要求医院数字化转型，但现有研究缺乏对其内在机制的系统性解释。本研究聚焦珠三角六家医院儿科，旨在破解不同机构在技术采纳、资源配置等方面的分化逻辑，为优化区域医疗数字化提供理论支撑。

研究整合创新扩散、制度理论及复杂适应系统理论，通过深度访谈采集质性数据，运用三级编码提炼核心范畴，并结合 fsQCA 分析多因素配置效应。构建“动态平衡模型”，聚焦领导-运营，区域经济、用户特征等五大前因变量，解析宏观政策与微观运营的交互机制。

研究表明，儿科数字成熟度差异由多因素动态交互所致：公立医院依赖自上而下推动，区域经济与政策影响资源分配；年轻父母高数字素养降低技术壁垒，组织文化差异导致学科路径分化；私立医院以个性化服务建立信任，小型医院依赖政府资金。“动态平衡模型”识别出“适应性阈值”，强调技术投资需与组织准备度匹配以避免系统摩擦。

理论层面本文整合多个理论，揭示制度压力、创新扩散与系统适应性的协同机制，完善数字成熟度评估框架。实践层面为政策制定者提供区域资源优化指标，帮助医院管理者设计差异化数字化路线图，推动儿科医疗向高效、精准、个性化转型。

关键词：儿科医院；数字化成熟度；动态平衡模型

JEL: I12; M15

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I want to thank my husband, whose unwavering support has strengthened my belief in love and dispelled my fears about marriage and childbirth. His encouragement is my backbone that propels me forward.

To my daughter Minka, your arrival has given me the drive to strive for excellence.

Among my classmates, one mother pursued her doctoral studies to tell her daughter, who was preparing for entrance exams, that learning is a lifelong endeavor, not something to be overly concerned about at any single moment.

I pass on the same message to Minka: Life is a vast wilderness, not a set track. After experiencing various lifestyles and witnessing countless beautiful scenes, I still find joy in academic research. Progress is a lifelong pursuit, one that should be approached with ease and without limits.

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致　谢

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我的同学里有一位妈妈读博的初衷就是告诉她面临升学考试的女儿: 学习是一辈子的事儿, 不必过分在意一时一刻的成绩。

我也把同样的话寄予 Minka——人生是旷野, 不是轨道, 妈妈在尝试过种种生活方式看过无限风光之后, 仍能在学术研究中找到快乐。进步是一辈子的事儿, 从容含玩, 进无止境。

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Chapter 1: Introduction

1.1 Research background

1.1.1 Hospital digitalization

Digitalization technology applications represented by the Internet of Things, big data, artificial intelligence, and cloud computing are profoundly affecting the business modes of various enterprises and organizations and promoting business transformation and mode innovation. Therefore, digitalization has become a hot topic in various industries in recent years (Joshi et al., 2025; Rane et al., 2024). In summary, its connotation is the deep integration of digitalization technology and business, the establishment of new or reshaped business modes, and the creation of new value. Its technological essence is to map the physical world into a digital space through digital technology, process and analyze data in the digital space, and use the analysis results to guide physical world activities (Bharadwaj et al., 2013; Ponomarenko et al., 2024). The establishment of digital space and the reliance on the digital space to drive business activities is the symbol of the development from traditional digitalization to digitalization (Plečko et al., 2023). Taking ride-hailing services as an example, it has established a new online and offline combined call-and-ride service mode through cloud platforms and mobile technology, connecting and dispatching taxi resources through the service platform, improving service efficiency and user experience, and realizing the digitalization of the traditional taxi industry (Tang, 2021; Vega-Gonzalo et al., 2024).

Hospitals are a typical traditional industry centered on knowledge-intensive diagnosis and treatment services, and supported by traditional management and operation of people, finance, and materials (Liao et al., 2023). After years of development, hospital digitalization has become the infrastructure for hospital operations. It plays an important role in optimizing processes, improving efficiency, strengthening management, and improving services (Aini, 2024; Saifudin et al., 2021). Hospital digitalization construction is actually the process of the acceptance, adoption, and specific application and dissemination of its digitalization innovation, that is, the process of the innovation diffusion of hospital digitalization (Burmann et al., 2023; Putteeraj et al., 2021). However, the application of digitalization in the medical field is a new thing, and the promotion and application process of a technological innovation must be subject to various constraints (M. Hassan et al., 2024). In the digital age, under the background of digitalization in various industries, understanding what factors affect the innovation diffusion of hospital digitalization and how to improve the popularization rate of digitalization has become one of the concerns of hospitals, enterprises, and policymakers.

1.1.2 Development status

The scale application of hospital digitalization systems in China began in the mid-1990s and went through two stages of free development and government promotion. In the past decade, health authorities have vigorously promoted medical digitalization by using the application-level evaluation of electronic medical record systems as a lever. In recent years, the competent authorities have issued a series of policy documents to promote the comprehensive expansion of hospital digitalization construction from focusing on electronic medical records to paying attention to patient services and hospital management. Through strong policy promotion and continuous efforts by hospitals, the digitalization level of Chinese hospitals has been rapidly improved (Z. Hu et al., 2024; Liang et al., 2020). From 2018 to 2019, the average level of hospitals participating in the evaluation of electronic medical record system application level increased from 1.74 to 2.43, and the level of tertiary hospitals increased from 2.59 to 3.46 (Zhuang et al., 2019). Various forms of patient visit services have emerged, and internet hospitals have flourished. Hospital management digitalization has entered a new stage based on data supervision, and operation management has become a new hotspot of hospital digitalization. From the perspective of digitalization, an analysis of the current development of hospital digitalization reveals the following significant achievements (Gastaldi & Corso, 2012; Guo & Liang, 2021).

1.1.2.1 Main businesses of hospitals have been digitized

Large hospitals, especially those at the forefront of digitalization technology, have basically achieved digitalization of their businesses. This is mainly reflected in three aspects: a). in terms of data collection, major medical equipment such as testing, imaging, electrocardiography, and monitoring have been digitized and automated. Businesses in the field of clinical treatment, medical technology, security, management, services, and office have all been computerized. Patient medical records, patient visits, medical business activities, and human, financial and material operations are comprehensively recorded, and some hospitals have even implemented study fewer work modes (Islam et al., 2018). b). in terms of data sharing, integration has been achieved among heterogeneous business digitalization systems, and data sharing has been implemented among business links. Workflow has been optimized based on networked collaboration, and a closed-loop work mode for medical orders is being formed (Torab-Miandoab et al., 2023). c). in terms of data analysis and application, statistical analysis of hospital efficiency, quality, performance and other indicators have been widely carried out (Mirescu et al., 2023). Some hospitals have explored intelligent applications such as image AI, CDSS, medical record quality control, and big medical data analysis for clinical study (M. Chen et al., 2024; Fan et al., 2024). Overall, digital space for hospital business activities and medical records is taking shape, providing a foundation for further innovation in business and management modes.

1.1.2.2 Application goals mainly focus on improving efficiency

In recent years, the development of hospital digitalization has mainly revolved around the digitalization of business processes and the integration of business flows (Grüttner, 2021; Saifudin et al., 2021). The requirements for electronic medical record system application-level evaluation standards below Level 5 mainly reflect digitalization sharing and process integration. The *Report on the Status of Hospital digitalization in China* pointed out that "optimizing business processes and improving medical efficiency" always rank first in the role of digitalization systems in hospitals and the most important issues that the application of digitalization technology should solve (China Hospital Information Management Association, 2021), which also indicates the main focus of hospital digitalization application during this period. The application of digitalization has significantly improved hospital work efficiency. For large hospitals, a daily outpatient volume of tens of thousands of people is not uncommon (Stoumpos et al., 2023). Outpatient doctors can see dozens or even hundreds of patients a day, which relies on the support of doctor workstations and data sharing tools. Self-service and mobile phone services that greatly reduce patient waiting in line are also indispensable (Poissant et al., 2005). This effect is achieved by replacing manual recording with computer recording and replacing the manual study transmission with networked transmission and sharing of data, without fundamentally overturning the original business mode.

1.1.2.3 Initial effects of partial digitalization are emerging

While improving work efficiency, innovative patterns in partial business processes are beginning to emerge. In terms of patient services, patients can complete registration in advance at home through mobile phone appointments; some patients with chronic diseases can receive online medical treatment and enjoy home delivery services through Internet hospital platforms (X. Huang et al., 2024). In terms of management, a new quality management mode has been established based on data analysis for medical quality supervision, such as automatic monitoring of nosocomial infections and internal quality control of medical records (Shenoy & Branch-Elliman, 2023). This has changed the way of relying on manual audit sampling, and digital supervision is more comprehensive, real-time, and accurate. In terms of material support, the sharing of inventory digitalization of medical supplies inside and outside the hospital has been achieved by relying on drug and consumables supply chain platforms, and automatic replenishment and distribution services of drugs and consumables have been implemented on this basis (Shen et al., 2024). However, overall, the above business transformation occurred in the local or peripheral business processes of the hospital, and the medical treatment model of "registration-triage-treatment-payment-examination-treatment" has not undergone fundamental changes, and the clinical medical model of "inquiry-physical examination-test-diagnosis-treatment" has not changed. The core medical and service models of hospitals have not yet undergone digitalization.

1.2 Research problem

The research dilemma of this study: The effectiveness of digital transformation in hospitals can't be accurately measured and defined, given the proliferation of government policy documents that mandate such transformation but lack consistent evaluation criteria. In recent years, China has issued a series of significant and normative documents related to digitalization, digital health, and smart hospitals. In March 2021, the *14th Five-Year Plan for National Economic and Social Development and Long-term Goals for 2035* emphasized the need to accelerate digital development and build a digital China, with a particular emphasis on creating new advantages in the digital economy and promoting industrial digitalization (Political Bureau of the Central Committee of the CPC, 2021). In January 2022, the State Council released the *14th Five-Year Plan for Digital Economy Development* which explicitly called for accelerating the development of digital health services and promoting the digitization and intelligent transformation of medical institutions (State Council of the People's Republic of China, 2022). In January 2022, the *Digitalization 2.0 Plan for Convenient Medical Services* was issued by the Shanghai Municipal Government, which includes seven major application scenarios, three innovative highlights, and five measures, aiming to build an innovative demonstration hospital district that is different from traditional smart hospitals, with the themes of digitalization, high-quality development, and convenient medical services (Shanghai Municipal Health Commission, 2022). In June 2021, the *Opinions of the State Council Office on Promoting the*

High-Quality Development of *Public Hospitals* explicitly called for strengthening system innovation, technology innovation, model innovation, and management innovation in public hospitals, as well as promoting the deep integration of new technologies such as cloud computing, big data, the Internet of Things, blockchain, and 5G with medical services (General Office of the State Council of the People's Republic of China, 2021).

The goal of pursuing high-quality development in hospitals is to improve the quality of medical care, patient experience, and cost-effectiveness. The effective way to achieve these goals is to transform data into data assets through digitalization, becoming the core asset and foundation of high-quality hospital construction. Achieving high-quality development in hospitals requires an innovative path by utilizing digital innovation to reshape hospital business processes, organizational activities, service models, and employee capabilities, thus injecting new vitality into high-quality hospital development and accumulating competitive new advantages, thereby promoting the hospital's leapfrog development.

However, the actual effectiveness assessment of digital transformation faces multiple practical challenges.

From an evaluation perspective, there is a significant systemic deficiency in digital maturity assessment frameworks. Although national guidelines like the Hospital Smart Management Tiered Evaluation Standards have been issued, healthcare institutions exhibit fragmented evaluation practices in implementation: some adopt internationally recognized HIMSS (Healthcare Information and Management Systems Society) ratings (Sivaramakrishnan et al., 2023), while others use localized EMRAM (Electronic Medical Record Adoption Model) systems (Kose et al., 2020), resulting in insufficient comparability across assessments. A more fundamental contradiction lies in the multidimensional nature of medical digital transformation, which spans 12 critical domains including infrastructure, workflow optimization, data governance, and patient-provider interactions. Yet, no comprehensive three-dimensional evaluation system currently exists to measure investment intensity, application depth, and integration breadth.

The ambiguity in outcome determination stems from the inherent complexity of digital transformation. While hardware investments can be quantitatively tracked, the translation of clinical value remains difficult to monetize or standardize.

In management practice, challenges manifest as follows:

Hospital administrators face cyclical dilemmas in strategic decision-making—unable to rely on traditional IT project evaluation criteria while lacking tools to assess digital value creation (Brossard et al., 2022).

A disconnect persists between IT departments' hard metrics (system deployment rates, data collection volumes) and clinical units' soft experiences (rounding efficiency, closed-loop order management), with no unified conversion framework bridging these dimensions (Zheng et al., 2010).

This impasse breeds two extremes: some institutions engage in ratings-driven performative efforts, while others delay critical system upgrades due to evaluation uncertainties. The solution requires shifting focus:

1.From device coverage to human-machine collaboration depth

2. From data storage capacity to knowledge conversion efficiency

3. From technical sophistication to tangible clinical benefits

The revised evaluation framework must accommodate the complex entropy of healthcare services, balancing standardization with customization while addressing transformation disparities across different hospital types.

1.3 Research questions

Therefore, we translate the real-world management challenges into concrete research questions.

(1) What are the dimensions of pediatric hospital digital transformation, transformation process, and transformation outcome?

The process explores, builds, and expands (Informatization, Digitization, Intelligence). The most important outcome is the maturity of digital transformation in hospital pediatric departments. Outcome of transformation. Other outcomes may include hospital traffic, patient satisfaction, efficiency of care, and so on.

(2) How do pediatric hospitals of different types and levels differ in their digital transformation process and outcomes?

Types mean special hospital vs. general hospital, private vs. public, large vs. small scale hospital, and independent vs. affiliated hospital. I will define and effectively measure the difference.

I will also discuss the factors contributing to these differences and the consequences they have led to.

(3) What are the relationships among pediatric hospital digital transformation antecedent factors, processes, and outcomes?

The moderating variables among factors and processes include the location, scale, and nature of hospital customer flow and patient demand, organizational promotion and acceptance, management drive, organizational size, and type. Additionally, changes in external policies, conflict over benefit distribution, and institutional contradictions play a role.

The moderating variables between the process and the outcome include digital talent, digital governance, communication channels, the emergence of new technologies, incentive mechanisms, perceived ease of use, and perceived usefulness.

1.4 Research purposes

The research approach of this study is to view cases through a theoretical perspective, and then transform abstract theories into a framework more suitable for hospital pediatrics by applying cases, resulting in a model more specific than the theories. By comparing the driving factors, pathways, and maturity of digitalization diffusion in pediatric departments of Six hospitals (of different types and at different levels) in the Pearl River Delta, the study analyzes their differences in strategy, technology, processes, resources, culture, data governance, and digital ecosystems. It examines these differences across various dimensions, such as conceptual innovation, organizational assurance, and digital foundations, so as to track changes over different years or stages. The study aims to identify the factors causing these differences and explore the outcomes resulting from these disparities.

In May 2020, the National Health Commission issued the “Notice on Further Improving the Appointment Diagnosis System and Strengthening the Construction of Intelligent Hospitals,” based on the “Hospital Smart Service Grading Evaluation Standard System” and the “Electronic Medical Record System Function Application Level Grading Evaluation Methods and Standards” (S. Zhang et al., 2024) This notice proposed the establishment of an intelligent hospital system integrating intelligent medical care, intelligent services, and intelligent management, with electronic medical record construction being the core of intelligent medical care

Studies on hospital information system construction: Moghaddasi et al. (2018) elaborated on the construction of hospital information system architectures, dividing the applications into three major systems: hospital management information system, clinical information system, and hospital service information system. They also identified the electronic medical record as the core of the doctor’s workstation.

This study concludes that digitalization in pediatric hospitals is essentially the shift toward a data-driven model. The foundation of this transformation includes data assets, data-driven practices, data-oriented thinking, and effective data utilization (Hornback et al., 2022). Central to these elements is data governance, which supports and strengthens them all. Pediatric digitalization is an intelligent pediatric hospital system integrating intelligent medical care, intelligent services, and intelligent management, with electronic medical record construction being the core of intelligent medical care (Y. W. Li et al., 2020).

Based on the theory of innovation diffusion, this study integrates the characteristics of hospital digitalization and applies the innovation diffusion theory to the promotion and application of hospital digitalization. The objective is to to address the research questions through a multi-case comparative analysis of pediatric departments in six hospitals in the Pearl River Delta, with specific objectives as follows:

1.Clarify the dimensions, process, and outcomes of pediatric hospital digital transformation

Focusing on the research question regarding the dimensions of digital transformation, this study will define the core dimensions of pediatric digitalization (e.g., infrastructure, clinical applications, management systems) and deconstruct the transformation process (from informatization to digitization and intelligence). It will also measure transformation outcomes with a focus on digital maturity, while supplementing other indicators such as patient satisfaction and service efficiency to form a comprehensive outcome evaluation system.

2.Reveal differences in digital transformation processes and outcomes across hospital types and levels

In response to the question about variations among different hospitals, this study will compare digital transformation pathways in pediatric departments of public vs. private hospitals, general vs. specialized hospitals, and large vs. small-scale hospitals. It will identify factors contributing to these differences (e.g., policy constraints, resource endowments, organizational culture) and analyze the consequences of such disparities (e.g., gaps in service quality, efficiency, and innovation capacity).

3.Explore the relationships among antecedent factors, processes, and outcomes of pediatric digital transformation

To answer the question about the relationships between variables, this study will construct a theoretical framework to clarify how antecedent factors (e.g., leadership, regional economy, user characteristics) influence transformation processes, and how process variables (e.g., technology adoption speed, organizational adaptation) affect outcomes. It will also examine the moderating roles of hospital location, scale, and policy environment in these relationships, thereby revealing the internal mechanism of pediatric digital transformation.

By achieving these objectives, this study intends to establish a theoretical model suitable for pediatric digital transformation, providing a basis for optimizing regional medical digitalization strategies and formulating differentiated development paths for hospitals.

1.5 Thesis structure

The research approach of this study is to view cases through a theoretical perspective, and then transform abstract theories into a framework more suitable for hospital pediatrics by applying cases, resulting in a more specific model than theories.

In the first chapter of this study, real - world management challenges are transformed into specific research questions. The second chapter is a literature review. Firstly, it reviews relevant basic concepts, including de - digitization, hospital digitization, pediatric digitization, and maturity. Secondly, it introduces the three major theories to be used in this study, namely the innovation diffusion theory, the institutional theory, and the complex adaptive systems theory. In the third chapter, theoretical construction is combined with empirical observation. Theories are used to guide empirical research, and in - depth interviews and comparative analysis are carried out. In the fourth chapter, interview data analysis and three - layer coding are used to confirm each other. The fsQCA analysis method is employed to further explore the interrelationships among complex variables in the digital transformation of pediatrics, and a dynamic balance model is finally obtained. The fifth chapter is the conclusion, including contributions, limitations, and prospects for future research.

For details, please refer to the technical flow chart. As shown in Figure 1.1.

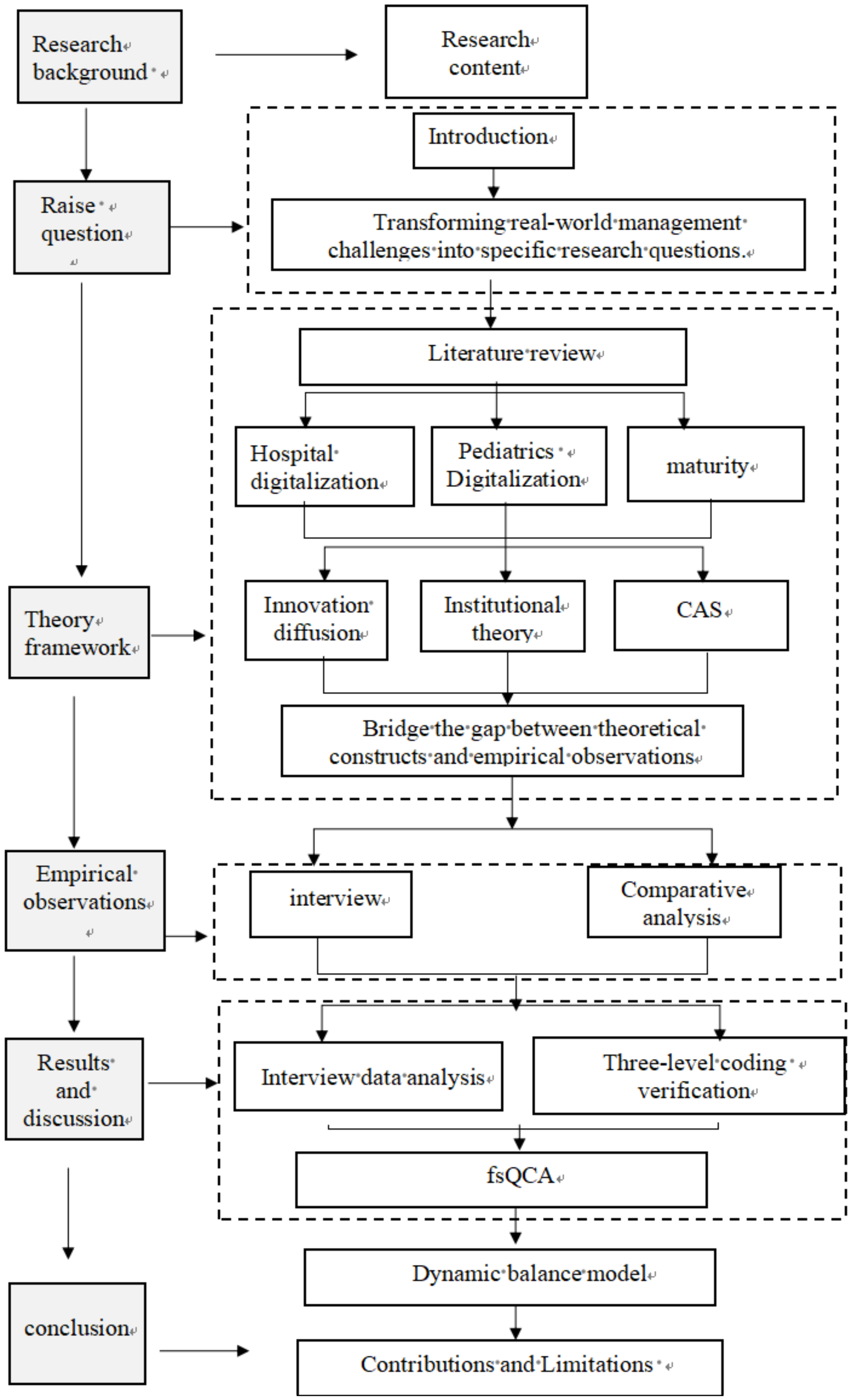

Figure 1.1 Technical flow chart

Chapter 2: Literature Review

2.1 Overview of hospital digitalization

2.1.1 Digital technology and digitalization

In computer terminology, digital technology refers to the process of converting images, text, sound, video, and other digitalization into binary data - represented by “0” and “1” - using specific devices, and then converting this data into a format recognizable by computers for storage and processing. From a technical application perspective, digital technology encompasses social media, mobile internet, data analytics, cloud computing, and the Internet of Things (Westergren et al., 2024). Some researchers assert that digital technology is represented by artificial intelligence (AI), blockchain, cloud computing, and big data technologies, collectively known as ABCD technologies (J. Wei & Zhao, 2021). Others highlight that the core of digital technology lies in operations based on “0” and “1”, and its complex characteristics such as interactivity, embedding, and editability introduce a new complexity to the digitalization and management systems of modern companies (L. H. Huang et al., 2021). This study aligns with the view of Langen (2016), which describes the new generation of digital technologies as comprising social, mobile, analytics, cloud, and Internet of Things technologies, collectively referred to as SMACIT, including big data, cloud computing, blockchain, IoT, AI, and VR technologies. The distinction between digital technology and traditional IT lies in their application purposes: traditional IT aims to improve business processes effectively, while digital technology fundamentally alters a company’s value creation model. It connects the supply and demand sides, enabling the upgrade and reorganization of the entire value chain, thereby enhancing operational efficiency, reducing costs, expanding business scope, and increasing revenues (Han & Li, 2022). Digitization is the process of applying digital technology. H. C. Wang et al. (2021) suggest that “digitization,” much like “mechanization,” “automation,” and “industrialization,” is an inevitable trend in social development and a continuous process. Yang and Cui (2022) define digitization as the process of using digital technology to process a company’s digitalization, thereby converting it into data. In this process, digital technology is essential for transforming digitalization into data. This study views digitization as the process of utilizing digital technology to convert the digitalization generated by enterprises into data, followed by its storage and utilization.

Currently, there is no unified definition for the concept of digitalization, but many researchers have provided their own definitions. Vial (2019) offered an in-depth summary of the meaning of digitalization, describing it as a process driven by various technological means of digitalization, computation, communication, and connectivity technologies, which results in significant changes to the nature of an entity, thereby improving the entity. This definition encompasses four key characteristics of digitalization: target entity, means, scope and extent of the transformation, and expected outcome. Based on the attributes included in Vial's definition of digitalization, this study categorizes them into the following four aspects: implementation subject, technological scope, transformation domain, and transformation expectation. Additionally, the definitions provided by Chinese researchers have been analyzed and studied. The results of this analysis are summarized in Table 2.1.

Table 2.1 Key literature review on the definition of digital transformation

Scholars	Viewpoints	Attributes
Morawiec and Sołtysik-Piorunkiewicz (2022) Wang et al. (2023)	Digitalization of enterprises refers to the activities of enterprises to improve production, operation and management by using relevant digital technologies such as artificial intelligence, blockchain, cloud computing and big data.	Implementation subject, technological scope, transformation domain
Reddy and Reinartz (2017) Ritter and Pedersen (2020)	Digitalization is the comprehensive and thorough transformation of enterprises organizational structure, research and production, business model through digitalization combination, computing, communication and connectivity technologies to trigger major changes in the attributes of enterprises, so as to enhance the ability and value efficiency of the transformation.	Implementation subject, technological scope, transformation domain and transformation expectation
J. Zhang et al. (2024) Li (2024)	Digitalization refers to the continuous transformation of the logic and process of traditional value creation by activating the attributes and functions of digital technology of enterprises.	Implementation subject, technological scope, transformation domain
Shahzad et al. (2025) Teng et al. (2022)	Digitalization of enterprises refers to the process of connecting and combining various digitalization and communication technologies to trigger major changes in the organizational characteristics, and reconstruct organization structure, behavior and operation system.	Implementation subject, technological scope, transformation domain
Gouveia et al. (2024) Wan et al. (2023)	Digitalization means that enterprises use modern digital technology to comprehensively change a company's strategic thinking, business processes, organizational structure and business model, create a value system with data as the core driving factor, and connect stakeholders to create value, so as to improve their market	Implementation subject, technological scope, transformation domain and transformation expectation

	competitiveness.	
Meng and Wang (2023) Kokkinou et al. (2024)	Digitalization is a process in which traditional enterprises add value to their production processes and consumers by using connected and analytical digital technologies (such as the Internet of things and artificial intelligence).	Implementation subject, technological scope, transformation domain

To further delve into digitalization, numerous researchers have conducted specific studies on the four attributes of digitalization: implementation subject, technological scope, transformation domain, and transformation outcome. Firstly, researchers have divided the subjects of digitalization into two aspects: macro and micro. The macro aspect refers to digitalization at the national or industry level. For example, B. W. Li et al. (2022) highlighted existing study deficiencies in digitalization from an industrial perspective, addressing applications, business, regulations, data, and collaboration. They outlined five study paths for digitalization within the industrial sector and provided an outlook on future study and national industrial policy directions. Another study analyzed modern systems theory and emphasized that to continuously advance digitalization in the governance of China, it is essential to follow modernization governance requirements and demonstrate institutional advantages (L. Zhang & Zhang, 2025). R. Huang et al. (2021), by constructing a nonlinear dynamic panel model, found that digitalization can rapidly enhance the cultural industry's level of sophistication, while long-term effects are influenced by the maturity of digital technology, relevant institutions, and environmental factors. The micro aspect focuses on digitalization within enterprises. For instance, Ni and Liu (2021) used text analysis techniques on annual reports from enterprises listed on the A-shares market from 2007 to 2018 to extract digitalization keywords and study its impact on corporate growth. Their findings indicated that digitalization promotes corporate growth, with a more significant effect on leading enterprises. Yao et al. (2022) suggested that enterprise digitalization involves leveraging a combination of digital technologies to trigger substantial organizational changes and improvements. This study specifically focuses on the micro aspect, namely the digitalization of hospitals.

2.1.2 From informatization to digitalization

2.1.2.1 Proposal and development of hospital digitalization

The concept of hospital digitalization emerged during the development of hospital informatization. As medical services constitute the core business of hospitals, hospital informatization is often referred to as medical informatization. The primary task of medical informatization is to achieve the digitalization of business operations and the automation of processes based on the establishment of information infrastructure. Although the concept of digitalization has been previously mentioned, the development of information technology, especially intelligent technology, has endowed "medical digitalization" with a new meaning. In the digitalization phase, medical services are comprehensively projected into the digital virtual world. This includes not just business nodes but also business processes and all related trajectories, ensuring that data records exist for every aspect. This projection leads to a symbiotic relationship between the physical and digital worlds (Z. Y. Li & Shi, 2023). With the accumulation of vast amounts of business data, it becomes possible to achieve data-driven business process optimization and intelligent decision support. Medical digitalization focuses on medical services and gradually expands to encompass all aspects of hospital business operations, including nursing services, scientific study, teaching, hospital management, and logistical services. This comprehensive approach forms the overall concept of hospital digitalization.

2.1.2.2 Hospital digitalization as an advanced stage of hospital informatization

Hospital digitalization represents not merely the mapping of the physical world into digital space through digital technology but also the genuine transformation of business models using digital technology, providing new opportunities for revenue and value creation. It is the process of transitioning to digital business. Digital business blurs the lines between the digital and physical worlds, creating new business designs. Xue (2022) argues that processing and analyzing data in the digital space can guide activities in the physical world. Yang et al. (2022) believe that clinical digitalization leverages data as a key element to achieve data-driven thinking. This approach allows for lower costs, higher efficiency, and more precise decision-making in clinical activities through the digital (virtual) means. During the process of hospital informatization, the nature and processes of business remain fundamentally unchanged compared to those of traditional methods. The reliance is more on the high integration of computer systems and efficient transmission by network systems to achieve data interconnection and partial automation of business processes (Yu, 2022). In contrast, hospital digitalization focuses on the collection and utilization of data. While informatization involves the digitalization of business operations, digitalization involves the transformation of data into business processes. Data-driven approaches are at the core of digitalization, making data a vital asset for hospitals (Zuo et al., 2022). With powerful data processing and analysis technologies, hospitals can achieve precise business analysis and promptly predict, identify, or develop new service capabilities. Especially with significant advancements in computational power and algorithms, data-driven artificial intelligence technologies have rapidly developed, making intelligence a prominent feature of medical digitalization.

2.1.3 Hospital digitalization

Digitalization in hospitals requires more than just using digital technology and achieving business digitalization. It also involves organizational changes across various departments, including personnel, knowledge and skills, finance, operations, and corporate culture, to ensure they can adapt to and embrace the transformation. This transformation involves benchmarking against industry standards, setting goals for each stage, and defining the ultimate objectives to align with the evolution of modern medical practices and healthcare service concepts. Digitalization is a shift, or even an upheaval, in thinking, aiming to provide higher quality and more efficient healthcare services. Researchers have explored hospital digitalization from several perspectives:

Basic theoretical study on hospital digital construction: The concept of a digital hospital was first comprehensively defined as distinguishing between the macro and micro definitions of digital hospitals, which laid the theoretical groundwork for the construction model of hospital informatization in China (G. X. Liu et al., 2004).

Importance and strategies for hospital informatization: Li (2014) emphasized the significance of hospital informatization and analyzed existing problems in the current hospital informatization. Based on these analyses, Li proposed corresponding strategies to address these issues.

Studies on hospital information system construction: Hu and Shen (2012) elaborated on the construction of hospital information system architectures, dividing the applications into three major systems: hospital management information system, clinical information system, and hospital service information system. They also identified the electronic medical record as the core of the doctor’s workstation.

Under the guidance of high-quality development, hospitals must strive to further enhance medical quality and safety, proactively shifting their operating models from extensive to refined management. In this process of transformation and upgrading, hospitals require support from informatization, digitalization, and intelligent systems (X. L. Zhang, 2021). Despite the increasing study interest in “digitalization” in recent years, hospital “digitalization” has not been as uniformly defined as “informatization” or “intelligentization” and the developmental relationships among the three are often confused and misunderstood. By reviewing relevant policies and literature (Z. Y. Li & Shi, 2023; J. W. Xu & Chen, 2022), this study clarifies the relationships among these three concepts. Hospital informatization serves as a solid foundation for hospital digitalization, providing essential data support for the application of artificial intelligence. It is a crucial component of the transformation process. Hospital informatization supports the internetization of hospitals, enabling effective connections between primary healthcare institutions and large international hospitals, thus initiating medical informatization and facilitating information sharing and flow. Hospital informatization is also the basis for hospital intelligentization. As a solid foundation for hospital digitalization, it provides data support for AI applications, while internetization is an important part of hospital digitalization, driving digital development (Yao et al., 2022). Hospital digitalization is a key process in promoting hospital intelligentization. Its focus is on the deep integration of medical services with big data and artificial intelligence, continuously optimizing hospital construction through the use of digital technologies and resources. Ultimately, hospital intelligentization emphasizes comprehensive improvements to ensure patient convenience, intelligent medical services, and refined hospital management. In May 2020, the National Health Commission issued the "Notice on Further Improving the Appointment Diagnosis System and Strengthening the Construction of Intelligent Hospitals," based on the "Hospital Smart Service Grading Evaluation Standard System" and the "Electronic Medical Record System Function Application Level Grading Evaluation Methods and Standards" (Medical Administration and Management Bureau, 2020). This notice proposed the establishment of an intelligent hospital system integrating intelligent medical care, intelligent services, and intelligent management, with electronic medical record construction being the core of intelligent medical care.

This study concludes that hospital digitalization is essentially the shift towards a data-driven model. The foundation of this transformation includes data assets, data-driven practices, data-oriented thinking, and effective data utilization. Central to these elements is data governance, which supports and strengthens them all. Digitalization in hospitals involves the deep integration of medical services with artificial intelligence and big data, and continuously optimizing hospital operations through the use of digital technologies and resources.

2.1.4 Measuring digitalization - maturity

In recent years, various methods have been developed to measure digitalization, including digital innovation patents, scales, and text analysis. Among these, maturity is a key method for assessing digitalization. The concept of digital maturity has gradually taken shape, providing a framework to describe the extent of digitalization (H. C. Wang et al., 2021). Digital maturity involves categorizing the stages of an organization's digitalization according to specific criteria, outlining the characteristics and conditions of each stage. It has become the most common method for assessing the extent of digitalization in organizations (Y. Lu & Wang, 2021). The existing digital maturity models primarily include the following:

1. China Academy of Information and Communications Technology (CAICT) - IOMM (Enterprise Digital Infrastructure Operation Maturity Model). This standard is used to evaluate the digitalization of enterprises from two perspectives: the operation capabilities of digital infrastructure and the overall digital operation capabilities of the enterprise. The evaluation of digital infrastructure operation capabilities is divided into six levels: service productization, capability platformization, data valorization, lean management, systematic operation, and risk transcendence. The evaluation of digital operation capabilities focuses on the enterprise's ability to technologically transform its capital, talent, production equipment, systems, and digital infrastructure during its operational processes. It includes aspects such as optimal resource allocation, cloud-based system collaboration, data analysis, and intelligent operations.

2. H. C. Wang et al. (2021) subdivided digital maturity into digital readiness, digital intensity, and digital achievement. Digital readiness indicates the organization's preparedness for change, digital intensity reflects the degree of the organization's digitalization, and digital achievement demonstrates the performance outcomes after the transformation. By selecting and summarizing key pathways and specific evaluation indicators, they developed the digital maturity model (DMM). The DMM mainly includes five key process areas: strategy and organizational structure, foundational infrastructure, digital development of business and management processes, integrated systems, and final digital performance. It comprises 19 primary indicators and 63 secondary indicators.

3. Deloitte divides the digital capability framework into six capability dimensions and five assessment levels. The six capability dimensions include strategy, demand, data, technology, operations, and human resources, each of which can be further subdivided. The assessment levels, ranked from low to high digital maturity, are cognition, exploration, application, systematization, and full transformation.

4. TM Forum's telecom digital maturity model evaluates the digital maturity of telecom enterprises across six dimensions: customer, strategy, technology, operations, organizational culture, and data. It includes 25 sub-dimensions and over 100 detailed assessment criteria to comprehensively evaluate the digital maturity level of the enterprise.

For the process of digitalization, researchers primarily focus on the paradigms of digitalization (Regan, 2022). Wei and Zong (2021) proposed that digitalization includes three stages: exploration, construction, and expansion. G. Cao et al. (2025) suggested that an organization's digitalization involves eight stages: decision-making, organization, digital mobilization, digital training, implementation, evaluation, benefits, and feedback. Lu et al. (2022) argued that digitalization is a top-down and step-by-step process where the organic combination of key actors and digital technology enables transformation. This process moves from "strategic cognition of initiators" to "collective cognition of key actors" to "collective cognition of executing actors" and finally to "achieving transformation." Ying et al. (2022) analyzed digitalization in manufacturing enterprises from different perspectives, emphasizing that digitalization involves the construction and dissemination of a new digital system logic at both organizational and field levels. In the early stages, manufacturing enterprises seek cognitive legitimacy, shift to normative legitimacy in the mid-stages, and eventually achieve regulative legitimacy, which in turn reinforces cognitive legitimacy. Many researchers use various perspectives to analyze the digitalization process, such as dynamic theory and resource-matching strategic evolution perspectives. Qian and He (2021) used Country Garden as a case study to illustrate that the digital transformation progresses through phases of digitalization, digitalization, and intelligentization. They also found that digital transformation in building dynamic capabilities follows an evolution process of "perceptive capability - acquisition capability - transformative capability." Wang and Mao (2021) examined the strategic evolution of resource matching, noting that enterprises achieve transformation in organizational structure, business processes, products, and business models through strategies of internal entrepreneurship, digital business strategies within the organization, and external collaboration strategies across organizations, ultimately rebuilding their competitive advantages in the industry.

The existing literature on digital maturity assessment methods can be broadly categorized into three types: case-based (Qi et al., 2021), questionnaire-based (H. C. Wang et al., 2021), and quantitative statistical (S. C. Liu et al., 2021; Xie & Wang, 2022). Study methods commonly use multi-indicator evaluation and analytic hierarchy process.

Vial (2019) summarized a digital transformation framework spanning eight construction modules. Chanias et al. (2019) conducted study on the formulation and implementation of digital transformation strategies (DTS). C. F. Zhang and Xue (2023) constructed an evaluation index system for the development level of digital transformation in manufacturing enterprises based on innovation-driven approaches. Zheng (2018) analyzed and summarized the key aspects of manufacturing enterprises transitioning to Industry 4.0 based on the acatech Industry 4.0 maturity model, which consists of six stages. R. Wang and Dong (2019) developed a digital maturity assessment model for manufacturing enterprises from four dimensions: strategy, operational technology, cultural organizational capabilities, and ecosystem. H. C. Wang et al.

(2021) developed a digital maturity model (DMM) comprising five key process domains (strategy and organization, infrastructure, digitalization of business processes and management, integrated integration, digital performance), 19 primary indicators, and 63 secondary indicators. Zou (2022) conducted study on the evaluation index system and model for the digital transformation capabilities of construction enterprises, establishing 25 measurement indicators and constructing a three-level evaluation index system for the digital transformation capabilities of construction enterprises. An evaluation index system was constructed for the digital development level of Chinese construction enterprises from four dimensions: investment in digitalization, platforms, governance, and output (N. Zhang et al., 2023).

Researchers from both China and other countries have made significant progress in studying digital maturity, with a focus on evaluation index system frameworks and model study. However, qualitative analysis study on the maturity of hospital digital transformation is relatively scarce, and there is a lack of study on specific transformation steps. Existing studies mainly focus on transformation paradigms, making it difficult to standardize digital transformation methods. This study aims to further enrich and improve study methods and outcomes related to digital transformation.

The digital maturity model describes the expected evolutionary path of enterprise digital transformation from low to high levels based on maturity concepts, mainly comprising three parts: evaluation index system, evaluation methods, and maturity levels.

2.2 Innovation diffusion

2.2.1 From innovation to technological innovation

In our current era, it has become a common knowledge for everyone that innovation plays an indispensable role in every aspect of life and work. Tracing back in history, as early as 200 years ago, Adam Smith (1776) recognized the role of innovation. However, innovation as a systematic theory emerged in the early 20th century through the research of Schumpeter. After the two world wars, people increasingly realized the importance and significance of innovation for societal development, resulting in a surge in related research literature.

Schumpeter argued that production involves combining materials and forces, and new combinations of these elements that appear discontinuously and exhibit developmental characteristics are central to innovation. Schumpeter distinguished five types of new combinations: (1) a new good; (2) a new method of production; (3) a new market; (4) a new source of supply of raw materials; (5) (the carrying out of) a new organization of any industry (or market). These five forms of innovation are well-known today. In the appendix "Analysis of Economic Change", Schumpeter summarized the concept of innovation as a change in the production function that cannot be decomposed into infinitesimal changes. Schumpeter was the first economist to use "innovation" to explain economic development, pioneering "the theory of innovation".

In 1912, innovation theory was first introduced by asserting that innovation is a variation in the production function (Schumpeter, 2009), involving the introduction of unprecedented new combinations of production factors and conditions into the production system, thereby achieving excess profits and driving economic development. Schumpeter's innovation theory included five new combinations: introducing new products, adopting new technologies, opening up new markets, sourcing new supply origins, and implementing new organizational structures. Innovation is the process of generating, developing, and implementing new ideas or behaviors, encompassing new products or services, new process technologies, new organizational structures or administrative systems, and new programs or plans related to organizational members (Damanpour, 1996).

Scholars from different fields have conducted in-depth research on technological innovation, offering various definitions. Solow (2015) comprehensively studied technological innovation theory, viewing it as an endogenous variable of economic growth and a fundamental factor. He emphasized two preconditions for technological innovation: the source of new ideas and subsequent development stages. Freeman (1977) defined technological innovation as the first commercialization of new products, processes, systems, and services. Arthur (2009) argued that all new technologies emerge from the combination of existing technologies, which have the self-generating ability to produce new technologies. The mechanism of technological evolution is thus combinatorial evolution, making technological innovation a form of combinatorial innovation. Fu (1998) distinguished narrow technological innovation from broad technological innovation, with the former starting from R&D and ending in market realization, while the latter begins with inventions and ends with technology diffusion. Xu (2000) emphasized that technological innovation is not just a technological invention and success but also includes personal and organizational factors influenced by environment, participants, and locations. Coccia (2015) posited that gaining a market competitive advantage is the main purpose of technological innovation. To maintain this advantage, enterprises must continually seek new solutions to problems and sustain innovation. Technological innovation involves the creative integration of knowledge necessary for the emergence of new technologies, with knowledge being the core of technological innovation (Dou et al., 2025). Technological innovation consists of activities leading to new technologies, expressed through the emergence of new knowledge and its integration with existing knowledge. The new technologies resulting from technological innovation are outcomes of knowledge creation (J. Liu et al., 2020). In a knowledge-based economy, technological innovation is seen by most enterprises as a primary strategy for sustaining business growth. In rapidly changing market environments, technological innovation is crucial for maintaining competitive advantage (Farida & Setiawan, 2022).

2.2.2 Definition and theoretical framework of innovation diffusion

Innovation diffusion is a concept closely related to technological innovation. A technological innovation will only impact economic and social development when it is widely adopted and utilized (Stoneman, 1981). Innovation Diffusion Theory emerged as a result of the development of productivity. At the beginning of the 20th century, new technologies and ideas emerged constantly, but people found that some innovative things were widely accepted and promoted, while others were gradually ignored and not diffused or applied. In the 1930s, hybrid corn technology was an innovative technology in agricultural planting in the United States. One-quarter of farms across the United States had started to use it and gradually promote it. Sociologists Bryce Ryan and Neal Gross conducted research on the diffusion process of hybrid corn planting and summarized the factors that influenced farmers' adoption of this new agricultural technology. They found that the channels and environment of innovation digitalization dissemination played a significant role in the diffusion of innovation. In the 1960s, American sociologist and communication scholar Rogers conducted research on the diffusion of innovation in various fields such as agricultural technology innovation, educational technology innovation, and medical technology innovation. He published the book *Diffusion of Innovations*, systematically explaining the theoretical system of innovation diffusion and laying the theoretical foundation for it. Rogers (2015) continued to revise and develop this theory after that.

Like the spread of infectious diseases, the more enterprises adopt a technological innovation, the greater the impact on those enterprises, and the more likely other enterprises will adopt the innovation (Mansfield, 1961).

The learning theory of technological innovation diffusion posits that the spread of technology is far more complex than the dissemination of digitalization, involving processes of adoption and learning. Technological diffusion is the promotion and application of a new technology, which is an autonomous innovation process based on the relationship between costs and benefits (Stoneman, 1981). It is also a continuous learning process. Like new ideas, it often requires time to resolve and develop certain technical issues (Komoda, 1986). Enterprises adjust the uncertainties of adopting innovations by learning from the experiences of other companies that have already adopted the technology, thereby mitigating potential risks (Z. X. Zhou & Li, 2002).

The substitution theory of technological innovation diffusion suggests that the diffusion of technological innovation primarily involves replacing an old form of satisfaction with a new one, which can be represented by a substitution model of technological change (Fisher & Pry, 1971). When adopting something new, people often need to abandon existing things. A significant number of ideas, products, and behaviors are disseminated through substitution (Jin et al., 2019). Therefore, the process of technological innovation diffusion is essentially the process of new technology replacing old technology.

The selection theory of technological innovation diffusion views the diffusion process as a selection, where enterprises choose from multiple alternative technologies based on certain principles. The ultimate choice of technology is largely determined by the prevailing techno-economic environment. In addition to the various levels of technology selection by enterprises, the theory also includes the choices made by customers regarding the enterprises (Metcalfe, 1981).

The evolutionary theory of technological innovation diffusion argues that economic behavior evolves along conventional lines rather than rational ones. This dynamic evolutionary process of technological innovation diffusion is characterized by irreversibility, irregular diffusion patterns, bounded rationality, and endogeneity (Nelson & Winter, 1982).

Technological innovation diffusion has a time effect, being a continuous sub-process in the overall process of technological innovation, as well as a complete and independent process that combines technology and economy (Wu et al., 1997). It occurs after invention and technological innovation, relating to the market promotion and dissemination of the technology (Freeman, 1977). The diffusion process can be analyzed from three aspects: research and development diffusion, the diffusion of innovative ideas, and the diffusion of technological innovation implementation (Fu, 1998). Additionally, some scholars emphasize that technological innovation diffusion includes spatial effects. From a spatial perspective, it refers to the geographical spread or transfer of technological innovation, encompassing the promotion, absorption, imitation, and improvement of technology (Jefferson & Rawski, 1994). The phenomenon of patent citations is often accompanied by knowledge spillovers and diffusion.

By comparing the geographic locations of citing and cited patents, one can measure the extent of knowledge diffusion (Jaffe et al., 1993). Through combining the above studies on the theory of technological innovation diffusion, this study defines it as the process by which a new idea or technology spreads from its source to adopters or users, eventually replacing old ideas and technologies through continuous learning and imitation. In the context of this research, it pertains to the spread and adoption of digital transformation in hospitals.

Innovation refers to a new method, practice, or object that is perceived as entirely new by the adopters. Communication is the process in which participants share and exchange digitalization to promote mutual understanding (Dong, 2010). Innovation diffusion is the process of innovation spreading among members of a particular social group over a period of time through specific channels. Innovation diffusion includes both active dissemination and spontaneous spreading. Technological Determinism holds that the diffusion of innovation depends on the superiority and advancement of the innovation itself, and the diffusion process is merely a process of users passively learning and accepting it (B. Liu et al., 2007). However, Rogers believes that having apparent benefits alone is not enough for an innovation to be diffused and accepted. The diffusion process of innovation also requires scientific testing to evaluate (Sáenz-Royo et al., 2015).

The diffusion of innovation is a process in which innovation is spreading through specific channels among members of a social system over a period of time. This process involves four main factors: the attributes of the innovation itself, diffusion channels, time, and social systems. These four factors are the main factors in the process of innovation diffusion, and research on these four factors constitutes the basis of the theoretical system of innovation diffusion.

(1) Attributes of innovation

Innovation brings uncertain digitalization to potential users during the diffusion process, and users evaluate the importance of innovation and form an attitude toward it before accepting it. The attributes of innovation include relative advantage, compatibility, complexity, trialability, and observability.

(a) Relative advantage: The relative advantage is the advantage that an innovation has over the method it replaces. The evaluation of relative advantage can be from the perspective of cost-benefit, as well as from the convenience, user satisfaction, and safety factors. However, the evaluation of relative advantage also has a strong subjective bias. In addition to the objective advantages demonstrated by innovation, whether individuals perceive its superiority is also very important. Objectively, the greater the relative advantage of an innovation, the earlier it is adopted, and the faster the speed.

(b) Compatibility: Compatibility is the degree to which an innovation fits with currently existing values, past experiences of potential adopters, and individual needs. An innovation highly compatible with the values of the social system is adopted much faster than an incompatible innovation. If an innovation is not compatible with the values of the social system, the diffusion speed will generally be slow because this innovation often requires the social system to change existing values or adopt a new set of values, which is usually a slow process of social development.

(c) Complexity: Complexity refers to the ease or difficulty with which an innovation is understood or used. Some innovations can be easily understood and used by most individuals in a social system, while others are very complex and difficult to adopt.

(d) Trialability: Trialability is the possibility that an innovation can be tried under specific conditions. An innovation with trialability has greater persuasive power for those considering adopting it. People learn about and understand the content of innovation through trial. If the trial process does not meet the potential user's expected needs, they may choose to reject adoption.

(e) Observability: Observability for adopters refers to the visibility of the results of an innovation's output. The more visible the results of an innovation, the more likely people are to adopt it. Visibility can also lead to discussion and communication about the innovation among people, such as friends and relatives of adopters who may seek their evaluation of the innovation. Therefore, if potential users perceive that an innovation has great relative advantage, good compatibility, trialability, and is not complex, they will be more likely to adopt it.

(2) Disseminating channels

Dissemination channels refer to the pathways through which digitalization spreads from a source to individuals or groups. The conditions and forms of these channels can greatly impact the effectiveness of digitalization dissemination. Mass dissemination is widely regarded as the fastest and most far-reaching means of spreading digitalization, enabling rapid diffusion of innovative ideas across a broad audience and achieving widespread acceptance. Additionally, interpersonal channels can effectively persuade individuals to adopt new innovations, particularly when individuals in the interpersonal environment share similar status and education levels, leading to imitation among peers. Informal communication between individuals is an essential channel for disseminating experiential knowledge (Z. H. Hu & Liu, 2002). Therefore, the diffusion of innovation is a social process.

(3) Time of diffusion

Time plays a crucial role in the process of innovation diffusion. It includes several time factors such as the decision-making process, the timing of individual or organizational adoption, and the speed of adoption within a system. The decision-making process for individuals to adopt or reject an innovation can be broken down into five stages: knowledge, persuasion, decision, implementation, and confirmation. During the Knowledge stage, individuals or organizations become aware of the innovation and understand its content. Persuasion occurs when they process the innovation digitalization and form an attitude of acceptance or rejection. The decision stage is when individuals or organizations confirm their adoption attitude and decide to accept or adopt. Implementation is when individuals or organizations put their decisions into action and use the innovation. Confirmation is the decision-making process for the next adoption behavior, during which individuals or organizations may make decisions to continue or terminate adoption based on favorable or unfavorable digitalization.

(4) Social system

The social system consists of individuals, groups, institutions, government organizations, and other entities. Innovation may have different diffusion effects in different social systems, even under the same communication channels. The structure of the social system can either promote or hinder the diffusion of innovation. Differences in the policy environment, innovation promoters, and interpersonal environment within a social system can also impact the degree and pace of innovation diffusion.

(5) Personal factors

Apart from the four factors mentioned earlier, the personal characteristics of potential adopters can also impact the diffusion process of innovation. Based on the time of adoption and the characteristics of adopters, Rogers classified adopters into five categories: innovators, early adopters, early majority, late majority, and laggards.

2.2.3 The process and mechanisms of innovation diffusion

Technological innovation diffusion is a complex process that integrates technology with economics and markets. The diffusion of innovation can be broken down into five stages: knowledge, persuasion, decision, implementation, and confirmation (Sáenz-Royo et al., 2015). These stages are widely recognized and used as a theoretical framework in research.

2.2.3.1 The S-curve of technological innovation diffusion

Tarde (2005) first introduced the S-curve of innovation diffusion in 1904. He noted that when opinion leaders in a system begin to use an innovation, the S-curve starts to rise rapidly. Under the influence of these opinion leaders, other members of the system may imitate the behavior of adopting the innovation. According to his imitation rule, the closer an innovation is to an already accepted one, the easier it is for the new innovation to be adopted. Based on this, Mansfield (1961) quantitatively studied the diffusion of technological innovation by measuring the number of enterprises introducing new technology. He found that the growth in the number of enterprises adopting new technology over time fits a Logistic function. Therefore, the diffusion process in enterprises typically follows an S-shaped growth path. Other studies have analyzed the diffusion of technological innovation using the number of members adopting the innovation, discovering that it follows an S-shaped distribution over time (Sáenz-Royo et al., 2015). Initially, only a few individuals, known as innovators, adopt the innovation. The curve then rises as more members adopt the innovation in each time unit. Gradually, the curve levels off as the majority have adopted the innovation, and finally, it reaches a critical limit point, completing the diffusion. Further research integrates the relationship between investment and performance into the technological innovation diffusion model (Foster, 1986). After investing in new product or process development, initial progress is relatively slow. Once key knowledge is researched, rapid technological advancement occurs, known as the "take-off" phase. Ultimately, as the S-curve approaches its limit, further investment in developing the product or process will slow down technological progress and increase costs. Thus, technological investment needs to consider the stage of the technology lifecycle (Haupt et al., 2007). The entire diffusion process is closely related to the technology lifecycle, beginning with the invention or first commercial application of a technology, progressing through widespread adoption, and eventually being replaced by more advanced technologies (Fu, 1998). This lifecycle can be divided into four stages: emerging, growth, maturity, and saturation (Chang et al., 2009). Specifically, the diffusion of general-purpose technologies, such as artificial intelligence (AI), can be summarized into three stages: the identification and introduction stage, the production synergy stage, and the maturity stage. Cheng (2021) utilized the adoption rate of AI technology among American enterprises to illustrate this diffusion process.

2.2.3.2 Mechanisms of technological innovation diffusion

The term "mechanism" encompasses two attributes: first, the organizational components and their combination; second, the intrinsic connections or inherent regularities (Amaral, 1993). Introducing the mechanism into technological innovation diffusion essentially views it as an organic process. Studying its mechanism involves examining its internal functions, driving forces, and the process of system evolution. Technological innovation diffusion is a complex process interwoven with various subsystems of technological innovation and their interactions with the social environment elements (B. J. Wang, 2011). This interplay generates the driving forces of technological innovation diffusion. Simply put, the diffusion mechanism focuses on why technological diffusion occurs (J. Wang, 2010). External conditions involve the technological gap between supply and demand, while internal dynamics stem from the technology owner's decisions at different stages of the industrial technology lifecycle based on profit maximization. The receiving parties might introduce technology to gain economic benefits from innovation. The mechanism of technological innovation diffusion comprises supply and demand mechanisms, planning mechanisms, intermediary mechanisms, incentive mechanisms, and competition mechanisms. These five mechanisms simultaneously influence and jointly determine the diffusion pattern (Fu, 1998). Some domestic scholars have studied various components of the technological innovation mechanism. Zhu (1988) proposed the guiding mechanism of technological innovation diffusion, consisting of the driving mechanism, communication mechanism, and incentive mechanism. X. Cao and Cai (2013) identified the driving and incentive mechanisms as critical components, with the driving mechanism exploring the necessity and feasibility of technology diffusion and the incentive mechanism studying the direction, speed, and scope of diffusion. C. Y. Wu et al. (1997) believed that the driving force of technological innovation diffusion is the resultant force of driving and pulling forces. Innovators gain technological advantages and high profits, creating market competition pressure that drives innovation diffusion. Adopters pursue profit maximization, pulling the diffusion of technological innovation. Guan and Zhao (2003) suggested that incentive mechanisms could shorten the adoption process and increase diffusion speed. They proposed effective incentives for China's technological innovation diffusion: talent incentives and government financial incentives. Zhao (2005) used the principal-agent incentive theory to establish an analytical framework for environment-based technological innovation diffusion incentives. Zhao et al. (2008) proposed an incentive mechanism framework for technological innovation diffusion within enterprise clusters, providing a theoretical basis for collective measures to stimulate diffusion.

2.2.3.3 Models of technological innovation diffusion

Models of technological innovation diffusion use quantitative methods to describe the diffusion process, deepening and developing qualitative analysis. Numerous studies focus on these models, which can be categorized into macro diffusion models, micro diffusion models, and diffusion models based on complex networks.

Early models mainly approached diffusion from a macro system perspective. Mansfield

(1961) considered technology diffusion similar to the spread of infectious diseases, following a logical curve, leading to the S-curve diffusion model or the epidemic model. Bass (1969) developed the renowned Bass model based on the behavior of innovators and imitators, showing a bell-shaped trend in diffusion speed, different from the S-curve. Based on this, many scholars have analyzed, evaluated, and predicted technological innovation diffusion in enterprises (Chu & Pan, 2008; M. Lee & Cho, 2007; Turk & Trkman, 2012). Kwasnicki and Kwasnicka (1996) described an evolutionary model of the diffusion process based on biological analogies, using real data to identify its parameters. Shao et al. (2010) constructed a competitive diffusion model for industrial clusters based on the population survival competition concept.

Micro technological innovation diffusion models generally start from individual members of social systems, focusing on potential adopters' decision-making actions. Reinganum (1981) first introduced game theory into the study of diffusion models, finding that equilibrium in monopoly games leads to staggered adoption of new technologies by companies, resulting in a diffusion curve. Wan et al. (2006) built a coordination game model of technology diffusion based on innovation characteristics, discussing the impact of product performance and consumer heterogeneity on diffusion. B. Sun et al. (2019) constructed a game model of enterprise technology adoption decisions using agent-based models and evolutionary game theory, interpreting the formation and lock-in process of technology standards through diffusion evolution studies.

2.2.3.4 Overview of research paradigms

There are some distinctions in the focus of system usage and technology acceptance. “Acceptance” emphasizes the psychological decision-making process of individuals regarding the use of technology, including how various pieces of digitalization form beliefs and attitudes towards usage, and how these beliefs and attitudes determine usage intention and behavior. In contrast, “usage” emphasizes a relatively stable state of behavior resulting from the acceptance decision. “Acceptance” highlights subjective willingness, while “usage” emphasizes actual behavior, which is relatively stable. In this research field, several closely related concepts exist. “Adopt” refers to the process by which individuals and organizations recognize and implement new technology. According to Webster’s Dictionary, “accept” means “to take what is offered willingly, whether for pleasure, satisfaction of a claim, or duty”. Other similar concepts include “diffusion”, “usage”, “integration”, and “implementation”.

Building upon the empirical research on the Technology Acceptance Model, Venkatesh (2000) integrated various other models related to user adoption, including the Theory of

Reasoned Action, the Theory of Planned Behavior, the Innovation Diffusion Theory (IDT), and the Social Cognitive Theory. They proposed the Unified Theory of Acceptance and Use of Technology (UTAUT) in 2000.The UTAUT model proposes that users' intention to use a system is determined by three factors: performance expectancy, effort expectancy, and social influence. These factors are defined as follows:

Performance expectancy refers to the degree to which users perceive that the system will help them perform their job, and is determined by perceived usefulness, external motivation, job relevance, output quality, and result demonstrability.

Effort expectancy refers to the degree of ease with which users perceive that they can use the system and is determined by perceived ease-of-use, complexity, and simplicity.

Social influence refers to the degree to which users perceive that their behavior is influenced by the people around them, and is determined by subjective norms, social factors, and image.

Facilitating conditions refer to the extent to which users believe that the organization provides support for the successful use of the system in terms of relevant technology and equipment. It is jointly determined by perceived behavior control, facilitating conditions, and compatibility. The Technology Acceptance Model, in practical applications, studies users' acceptance behavior of technology from the perspective of how user intention influences usage behavior. Different influencing factors and different assumptions can better predict and explain users' acceptance and usage behavior of technology in different application environments (Y. Chen & Yang, 2009).

Compared to individual adoption studies, research on organizational adoption is less extensive. This disparity is due to the significantly larger sample sizes available for individual studies compared to organizational studies. In empirical research, individual data can be easily obtained through surveys and interviews, whereas obtaining comprehensive and unbiased data for organizations is challenging. Organizational samples often do not meet the required quantity for empirical research, resulting in a focus on theoretical studies. Tornatzky and Fleischer critically inherited the strengths of the diffusion of innovation theory and proposed the T-O-E (Technology-Organization-Environment) framework. This model posits that the adoption and innovation process of a technology within an organization is influenced mainly by three types of factors, namely external environmental factors, technological characteristics, and organizational conditions.

2.2.4 Review of innovation diffusion research

In summary, scholars both domestically and internationally have explored the diffusion of technological innovations from multiple perspectives. From the perspective of evolutionary diffusion, it is a complex process by which a technology spreads from innovators to adopters, transitioning from an emerging technology to rapid growth, then to maturity, and eventually saturation. Existing studies relatively seldom analyze the process of technological innovation diffusion from the perspective of complex networks or deeply delve into the mechanisms underlying this process. Therefore, it's a complex systemic issue to understand the exact diffusion patterns followed during the diffusion of technological innovations, and whether these patterns change over time. Innovation Diffusion Theory is a research result in sociology that initially focused on the impact of mass communication on innovation diffusion. With the continuous development of this theory, it has been widely applied to various fields such as agriculture, digitalization technology, education, and healthcare (D. W. Liu, 2006; 2014).

Currently, research related to Innovation Diffusion Theory is divided into macro and micro levels. Macro-level research includes the study of Innovation Diffusion Theory, the process of innovation diffusion, diffusion pattern research, and research on diffusion speed and its influencing factors. Micro-level research mainly focuses on individual innovation adoption decision-making, including the study of decision-making factors for innovation adoption, the process of innovation adoption, and its influencing factors. The research content can be roughly divided into three types: empirical research that combines specific environments and theoretical guidance, practical verification of specific influencing factors, and extension and validation of theoretical research

Innovation Diffusion Theory has been widely applied in the healthcare industry both domestically and internationally. It has been used to implement health education programs, conduct epidemiological investigations, and promote medical technologies.

In China, W. Z. Chen et al. (2006) applied this theory to health education for adolescents and improved the effectiveness of health education by controlling factors such as the dissemination time and channels. Other studies based on it have included promoting knowledge and techniques to prevent birth defects (T. S. Chen et al., 2020). C. J. Cao et al. (2008) applied this theory to the promotion and popularization of health support tools for residents and investigated the diffusion of HIV-AIDS risk behavior among male migrant workers. Dearing (2009) analyzed the promotion process of clinical pathways using Innovation Diffusion Theory. Internationally, Nicol (2011) conducted research on the diffusion application of blood glucose screening projects based on Innovation Diffusion Theory. Agyeman (2009) found that the time of adoption by the population of immunization against rotavirus was consistent with the S-shaped curve in Innovation Diffusion Theory through research. Gagnon (2016) combined this theory and the TAM to review the factors influencing doctors' adoption of medical digitalization technology and divided the results into promoting factors and inhibiting factors.

2.3 Institutional theory

2.3.1 Institutional economics

At an extremely abstract level, human economic and social development is a process of institutional evolution, and all the socio-economic changes are institutional changes. Under different assumptions and scenarios, institution can be equated with the environment, as well as a series of social, political, and economic arrangements. At the level of specific social action, institution is the fundamental constraint to regulate the change of social behavior, which ensures the possibility of occurrence, development, and change of different subjects' behavior, and makes the interaction of various social behaviors constitute a social process. In the view of contemporary new institutional economics, institutions are the "rules of the game" in a society (North, 1991). Although both the new institutional economics and the old institutional economics take institution as the main research object, their research methods, theoretical basis and value orientation are completely different. The former inherits the analytical framework of the mainstream neoclassical theory and stresses the internalization of the institution within this framework, while the latter completely breaks through or even abandons this framework and uses a unique perspective to analyze the role of institution in economic life. In some aspects, the views of the new institutional economics and the old institutional economics are the same, but their specific analysis angles and methods are different. For example, the new institutional economists inherit the tradition of neoclassicism, regard the existence of the market as the premise of institutional change, and believe that the market is not an organized entity, but a collection of individual exchanges. However, the old institutional economists believe that market does not exist naturally, and it is a social system controlled by a set of specific rules. Generally speaking, the old institutional economists study the changes of a single institution under the assumption that the institutional structure remains unchanged, while the new institutional economists focus on the historical change of the institutional structure itself. Specifically, the new institutional economics follows the efficiency standard of neoclassicism and holds that the institutional changes that can improve the efficiency of resource allocation are conducive to social progress, while the old institutional economics believes that institutional changes should be in line with the interests of the society as a whole. This difference can be attributed to the difference between individualism methodology and holism methodology followed by the two schools respectively. The difference between Marx's institutional view and the institutional view of the new institutional economics school lies in: (1) The system mentioned by Marx is composed of two interrelated components: the economic base and the superstructure. First of all, institution refers to the actual relation of production, which is a kind of objective social existence. The sum of certain social relations of production constitutes the economic foundation of society. The political, legal and other institutions and social ideologies established on this economic basis and that adapt to it are the superstructure of society. Marx distinguished the institution as the economic basis and the institution as the superstructure, and clarified the relationship between deciding and the decided, reflecting and the reflected. He pointed out: "The relationship of law with contract form is a relationship of will that reflects the economic relationship. The content of this legal relationship or will relationship is determined by the economic relationship itself" (Marx, 2004). New institutional economists do not make this distinction. They integrate various systems into a large institutional system and equate them. (2) Marx emphasizes that "the problem of ownership is the basic problem of movement" and holds that ownership adapted to specific productive forces belongs to the category of production relations and occupies the most basic layer of the economic institution. It plays a decisive role in other economic institutions and is the fundamental symbol to distinguish the nature of different social and economic institutions. In the view of the new institutional economists, ownership is an established premise, and different stakeholders constantly compare and analyze the expected income and expected cost under the established ownership premise. Therefore, they only emphasize the importance of property rights institution, national institution and ideological institution in economic development, and make property rights clear and absolute, believing that as long as property rights are clear, people will naturally improve efficiency. Making it clear the difference between Marx's institutional view and the institutional view of the new institutional economics school does not mean that they are completely opposite or separated from each other. In fact, the school of new institutional economics is influenced by Marx. According to Marx's point of view, the production of any society is carried out under certain production relations and institutional conditions, and the efficiency of different institutional arrangements is also different. The school of new institutional economics emphasizes the role of property rights institution, state institution and ideological institution in economic development and their influence on efficiency, which is similar to Marx's analysis. The new institutional economics school studies the emergence, development and change of the institution, reveals the dynamic and historical nature of the institution, and examines people in the complex relationship between institution and culture. These viewpoints are also close to Marx's views on the dynamic changes of the social system and some thoughts on the investigation of human behavior. The economic basis in the framework of Marx's institutional analysis is actually the economic rules and contracts related to production relations, distribution relations, exchange relations and consumption relations, that is, formal institutional arrangements. The ideology, including political and legal thought, morality and art, belongs to the informal institutional arrangement. The institution studied by the new institutional economics school is a series of norms that restrict people's behavior, which are formulated or created by human beings. They include not only written formal institutional arrangements such as political and legal institutions, but also informal institutional arrangements that exist only in the concept of human beings, such as morality, customs and habits implemented by human self-restraint and supervision by the public. Therefore, Marx's influence on the new institutional economics can be clearly seen.

2.3.2 Organizational and institutional complexity

Since the mid-1960s, the introduction of Open Systems Theory into organizational research has become an important symbol of the expansion of institutional theory in the field of organization. It emphasizes the impact of external institutional environment on organizational management, which is larger than the scope of the organization, and the external institutional environment plays a role in constraining, shaping, and transforming the organization. Since then, institutional and organizational researchers have argued that broader social and cultural factors or institutional environments also have a significant impact on organizations. In the process of continuous development of institutional theory, it constantly intersects and integrates with different disciplines such as economics, political science, and sociology, and the ideas and concepts of institutions have been continuously enriched and developed and combined with various organizational forms in the current era, presenting diversity, dynamics, and innovation. Early institutional theorists consider organizations as institutions that are infused with meaning, value, and legitimacy by their members and leaders (Jay, 2013). They define institutions by the rules of the game that govern social exchanges undertaken by individuals and organizations (North, 1991). Later, the neo institutionalism perspective criticizes the earlier arguments and argues that society is made up of inter-institutional systems, wherein multiple institutional orders coexist simultaneously, and each institutional order differentially influences individuals' and organizations' actions (Friedland & Alford, 1991). This shift resulted in the emergence of the concept of institutional logics, which is defined as "the socially constructed, historical patterns of material practices, assumptions, values, beliefs, and rules by which individuals produce and reproduce their material subsistence, organize time and space, and provide meaning to their social reality" (Thornton & Ocasio, 1999). Recent emphasis on institutional logics has, however, largely focused on how organizations respond to the multiple and even conflicting institutional logics that lead to institutional complexity (Durand & Thornton, 2018). Institutional complexity is the antagonism in organizational arrangements caused by those incompatible and conflicting institutional logics (Durand & Jourdan, 2012). In other words, when organizations are confronted with incompatible cognitive systems, institutional complexity emerges and makes it more difficult for those organizations to achieve a high consensus (Biesenthal et al., 2018). For example, in the innovation diffusion of hospital digital transformation, complexity comes from the institutional differences among actors, groups, political regimes, and the macro-environments that can bring about conflicts and uncertainty. Zelli (2011) argues that conflict is a particular type of institutional interplay within institutional constituents, and it has become more frequently discussed in governance literature. Coincidentally, Klijn and Teisman (2003) suggest that the institutional fragmentation of projects could create enormous barriers that could exacerbate the complexity of decision-making and call for a huge managerial effort.

Recent studies on institutional complexity from multiple disciplines have largely investigated the mechanisms by which institutional complexity affects organizations, and how organizations respond to institutional complexity. Institutional conflicts may lead to organizational breakup or paralysis (Pache & Santos, 2010). Durand and Hourand (2012) have outlined those conflicting demands in such a complex institutional environment are imposed upon organizations in order to meet the needs of the conflicting resource holder. Similarly, Raaijmakers et al. (2014) find that institutional complexity leads the decision makers to delay compliance, and usually not passively. Thus, the conflicting pressures in such an environment are imposed upon organizations by various institutional constituents who take different institutional logics and create incompatible demands but hold the critical "material" and "symbolic" resources in the organizations (Misangyi, 2016). In short, Raaijmakers et al. (2014) consider institutional complexity to come from particular conflicts that arise from differing institutional demands. When those different demands are incompatible or uncertain, the organizations may have difficulty maintaining institutional support (Pache & Santos, 2010).

Recent studies also have investigated the predictive factors of organizational responses, including the increasing social or economic returns for complying with the institutional demands (Greenwood et al., 2011; Oliver, 1991), the dependence on institutional constituents (Raaijmakers et al., 2014), the multiplicity of institutional demands (A. Martin et al., 2017), the consistency between institutional pressures and organizational goals (Kodeih & Greenwood, 2014), and the uncertainty of the context (Ramus et al., 2017), whether demands are legally coerced or voluntary (M. P. Lee & Lounsbury, 2015), it exists. When faced with institutional complexity, how do organizations respond to conflicting logics? Decision-makers' interpretation of institutional complexity and their personal beliefs can influence their choices, and the complexity can create ambiguity that forces the organization to adapt to it or act on it (Raaijmakers et al., 2014). When an organization is facing such institutional pressures (A. Martin et al., 2017), the ways to appropriately respond to institutional complexity could be the sources of competitiveness (Greenwood et al., 2011). The organizational responses to institutional pressures can vary from passive conformity to active resistance, depending on the nature and characteristics of the pressures (Oliver, 1991). From the perspective of comparative institutional analysis, complementary institutions shape a firm's strategy, innovation, internal structure, and external relationships, which are the sources of competitive advantage (Ahmadjian, 2016). Thus, how an organization deals with institutional complexity will be highly relevant to its comparative institutional advantages and will help the organization gain sustainable competitiveness.

2.3.3 Institutional pressure theory

In the process of development, organizations are mainly faced with the influence of institutional pressure and technological pressure. Institutional Pressure Theory suggests that organizations have the expectation of obtaining necessary resources or legal social status for survival, and organizations realize this expectation through the introduction of management measures. Although there are various definitions and connotations of the concept of institution in various branches of institutional theory, institutions generally exist and exert influence in the following forms, such as the standardized and compulsory institutions such as laws and regulations, as well as the non-mandatory behavioral consciousness and self-regulation (such as social morality and values) that exist in the social subjective ideology. The management measures introduced by the organization are intended to be consistent with such social factors, even though they are not necessarily economically efficient or unrelated to the organization's interests, such as serial and software maturity certifications; or the organization has an agreement with the authority that owns the organization's core resources on an involuntary basis. From the perspective of theoretical analysis, these institutional factors that have an impact on individual behavior include normative pressures, coercive pressures, cognitive pressures, and competitive pressures (Cai, 2006). These pressures can change the thinking basis (explanatory framework) of social members, such as values, knowledge, and habits. In order to be consistent with social expectations, organizations increase their legitimacy, resource accessibility, and viability by following social institutions to facilitate their survival and success. In conclusion, in a market economy that emphasizes competitive advantage, institutional theory explains why many organizations prioritize the pursuit of organizational legitimacy over the pursuit of organizational efficiency.

DiMaggio and Powell (1983) used institutional theory to analyze the reasons for the phenomenon of organizational assimilation in the study of organizational isomorphism, and proposed that institutional pressures include coercive pressures, normative pressures and mimetic pressures.

(1) Coercive pressures

The dependence of an organization on core resources can lead to coercive pressures, which can be simply summarized as the attitude and behavior of the organization in response to the demands made by the dominant party. The dominant party has the power to control social behavioral norms and has significant influence on organizations within the sphere of influence, including the behavioral expectations of dominant organizations and the cultural expectations of social norms. This expectation is imposed on organizations through formal or informal pressures, forcing them to adopt management systems, technologies, and models similar to those of strong organizations. Such pressure may come from public management institutions (policies, laws, and management systems of various organizations), or from organizations that have resources needed by the organization (such as core enterprises in the supply chain).

(2) Normative pressures

Normative pressures refer to a widely accepted standard of behavior within a society or industrial organization, which has a guiding effect on the behavior of members within a group. The source of normative pressures is professional standards and behavioral guidance. In order to obtain a certain legal status or behavioral permission, organizations accept normative pressures by exercising their responsibilities and obligations. Normative pressures are usually characterized by professional norms, which influence organizational behavior in the form of high-performance standards. Organizations meet the requirements of these norms through education and professional certification systems and generate ethical and moral requirements under the influence of these norms. In the real economy, normative pressures are common in the binary organizational channels of stakeholders (such as suppliers and producers, producers and customers), as well as through other professional structures. Normative pressure is a necessary condition for organizations to participate in social competition, but it is not as harsh as coercive pressures.

(3) Mimetic pressures

The source of the organization's imitation of other organizational behaviors is uncertainty, which works through the demonstration effect of other organizations, but it needs to be combined with interest factors to form a social behavior model with mimetic pressures and interest characteristics, especially for competitors. Organizations often face various uncertainties in the changing market environment, making it difficult to make reasonable decisions about future products, services, or models. At the same time, they are afraid of the risk of decision failure. Therefore, organizations reduce the cost of search and experimental risk by imitating behavior, avoiding the failure of being innovative pioneers. When organizations have doubts about whether it is necessary to implement technological innovation adoption activities, the observation of the behavior of competitors can ensure that even if innovation activities are not successful, it can at least ensure that they are not left too far behind by competitors. The adoption of digital transformation, i.e., diffusion, can be seen as a way of operation for organizations. When this mode of operation is repeated so that it becomes a widely accepted or default norm in society, and at the same time, it has the power to set institutional regulations or technical standards, it forms a mandatory or normative influence. The concept of trend pressure refers to the subtle influence of the cumulative number of adopters on the intention and behavior of adopters. Organizations tend to follow the trend of the times to adopt innovation, resulting in innovation diffusion. Trend pressures include the "normative trend pressures" to ensure organizational legitimacy and the "competitive pressures" to ensure the persistence of competitive advantages.

(1) Normative trend pressures

In the early stages of diffusion of technological innovation, after organizations rationally evaluate the returns and benefits of adopting innovation, the adoption decision will only be made if the returns and benefits are greater than the risk cost of adopting innovation. As more and more organizations adopt this innovation, subsequent adopters will form a psychological implication that the organization should adopt the innovation, and gradually ignore the value of the innovation in terms of technical necessity. The sense of identity within society or industry drives organizations to adopt innovation to align with other organizations. At the same time, organizations hope to reduce risks by following the trend of innovation. Based on the psychological drive of the above two reasons, organizations that have not yet adopted innovation may make innovation adoption decisions without rational thinking.

(2) Competitive pressures

On the one hand, organizations are concerned about losing their competitive advantage or falling behind the performance efficiency of the industry, and on the other hand, they expect to gain more competitive advantage or achieve excess profits. If the number of organizations adopting technological innovation in the industry continues to increase, organizations that have not yet adopted innovation tend to join the innovation queue. From the perspective of Resource Dependence Theory (RDT), the control relationship between organizations is a function of a series of resources. The strength of a power relationship between organizations depends on the degree of dependence on the resources provided by other organizations (Pfeffer & Salancik, 1978). The resource provider has the power to control the resource demander, so in the adoption activity, the resource dependence relationship can adjust the changes in the adoption intention and behavior of the resource demander. This influence is similar to the coercive pressures of institutional pressure, but RDT emphasizes the effect of its power relationship rather than its institutional factors, as shown in Table 2.2.

Table 2.2 Relevant pressures in institutional theory

	Institutional Assimilation Theory	Trend Pressure Theory	RDT
Coercive pressures	√		√
Normative pressures	√	√	√
Mimetic pressures	√		
Normative trend pressures			
Competitive pressures		√	

2.3.4 Differences between the rational school and the institutional school

There are mainly two schools of thought in academic research on diffusion: the rational decision-making school and the institutionalist school. Theory of Planned Behavior (TPB) and Theory of Reasoned Action (TRA) mentioned above belong to the rational decision-making school, which is based on the traditional research hypothesis of positivist philosophers, emphasizing that the cognitive process of organizations is accompanied by rational decision-making. Olikwoski (1992) advocates the study of technology and change in the process of technology adoption from a psychological perspective. Rational decision-making usually starts from the perspective of complete individual rationality, completely excluding the influence of environmental institutions on individuals. And the mixed rational perspective only considers environmental institutions as a common limiting factor. Rational Decision-making Theory holds that the rational behavior of countless individuals is combined into social phenomena. The rational decision-making school pursues institutional rationality, believes that technology should include structure, advocates the role of technology in promoting organizational change, and believes that technology can compensate for the shortcomings of human nature. The Rational Decision-making Theory believes that the purpose of the organization's adoption is to achieve the goal of maximizing organizational benefits, and that the decisions made or technology adoption after rational analysis should improve organizational productivity and performance and satisfy both the organization and individuals. If the above goals cannot be achieved, the organization will not make an adoption decision. If the actual effect after adoption is lower than expected, it indicates that there is a problem in the integration of adoption and the organization. The research of the institutionalist school rarely focuses on or emphasizes the role of technology itself, and usually focuses on the social evolution of the institutional structure of human society from a holistic perspective. Although institutionalism does not deny the reality that society is composed of individuals, it does not agree with the view that the simple superposition of individuals constitutes social phenomena in the micro perspective. Micro characteristics may not necessarily form consistent macro characteristics, such as the rational behavior of individuals being reflected as irrational behavior at the macro level, and institutionalism emphasizes that reasonable institutional settings can guide individuals to adopt rational behavior. Institutionalism tries to avoid the existence of individual factors in theoretical construction through conceptual substitution, as shown in Table 2.3.

Table 2.3 Research levels and dimension analysis of institutional theory

Institutional theory	Research level	Dimension analysis
Normative pressures	Social macro level	Based on the assumption of social holism, it is the core of institutional theory.
Coercive pressures	Middle level of organization	Achieved through intermediary activities between organizations
Mimetic pressures	Individual level	Avoiding individual rational behavior and substituting the choices of others for personal choices

The difference in research perspectives between the rational decision-making school and the institutionalist school lies in their understanding of the relationship between structure and agents. The rational decision-making school believes that the behavior of agents determines structure, while the institutionalist school believes the opposite. Both theoretical schools focus on result-oriented and ignore process-oriented determinism, with the difference being the determining relationship between "social structure" and "active subjects". Both rational decision-making and institutionalism have some shortcomings in analyzing the relationship between digitalization technology and organizational structure: digitalization technology is both the purpose and the result of organizational decision-making, which makes it not comprehensive enough to adopt the views of any school of theory alone.

2.3.5 Adaptive structuration theory (AST)

Due to the shortcomings of the rational decision-making school and the institutional school, organizational research scholars represented by Orlikowski (2008) have proposed the Technical Structuration Theory on the basis of the Structuration Theory of sociologists to compensate for the shortcomings of the two schools of thought since the late 1980s. The social technology school combines the content of the rational decision-making school and the institutional school, focusing on the research on the interaction and impact between innovative technology and social practice, rather than focusing on the role of a single aspect. It shifts from result-oriented research to process-oriented research. Giddens' dualism found a breakthrough in overcoming the dilemma of dualism, which is that on the one hand, the social structure itself is constructed by the actions of agents, and on the other hand, the structure is the intermediary through which actions can occur. Gidden's Structuration Theory emphasizes the duality of structure (agents utilize structure and modify or reconstruct it through structural features). Giddens defines the structure as "rules and resources", and the resources and rules that construct social structures are used by agents in their daily behavior. Therefore, agents not only utilize rules and resources, but are also strengthened and changed in the process of use. Although Giddens' theory does not explicitly state that the structure is digitalization technology, many scholars and studies have applied it to the study of organizational digital adoption.

Desanctis and Poole (1994) proposed AST based on the Structuration Theory, combined with the rational decision-making school and the institutional school, to explain the role of digitalization technology in the process of organizational change, and found that organizational structure change is closely related to agents' motivation of digital adoption. Orlikowski from the Sloan School of Management at the Massachusetts Institute of Technology (MIT) in the United States introduced the duality of structure into the study of organization and adoption, analyzing the organizational structure, the characteristics of institutions, and agents, and the paths of interaction among the three. Technology is not only a material structure constructed by actors under specific social norms for a certain workplace, but also a social structure constructed by actors by giving it different meanings and emphasizing its different characteristics in use. Orlikowski's structurational model of technology consists of four paths.

(1) Technology is the product created by people under specific social norms.

(2) People adopt technology as an intermediary tool for activities.

(3) Social norms influence the interaction between people and technology.

(4) The interaction between people and technology simultaneously affects institutions. As shown in Table 2.4 and 2.5.

Table 2.4 Specific applications of the structurational model of technology in the diffusion of digital transformation innovation

Path	Action mechanism	Migrated connotations in digital diffusion
1	Digitization as a result of actors	The demand for digitalization arises from organizational activities, so organizations have certain rational choice opportunities for digital diffusion, and at the same time, organizations need to have corresponding digital capabilities and allocative resources (Parviainen et al., 2017; Teng et al., 2022).
2	Counter-effects of digitalization on actors	Digital innovation diffusion is the intermediary of organizational activities, and the benefits of this diffusion will promote the adoption of digitalization by organizations. As an intermediary, it also needs to match the existing resources of organizations (S. S. Hassan et al., 2024; Testi, 2023).
3	The interaction between actors and digitalization is influenced by the characteristics of organizational structure.	The adoption of digitalization by organizations is influenced by institutions, and the adoption decision of organizations is affected by various environmental and institutional pressures, including normative and coercive pressures, and competition (Pattanaik et al., 2024).
4	The reaction of the interaction of actors and digitalization on the characteristics of organizational structure.	The process of organizational adoption has an impact on environmental institutions, so organizational behavior can change the institutional environment of other organizations, that is, the existence of partner influence, and form a competitive advantage through institutional rules that affect inter-organizational relations (Khan, 2024; Ngo, 2023).

Table 2.5 Influencing factors of structuration theory

Impact paths	Content	Factors that coincide with rational theories	Factors that coincide with institutional theory
The role of organizations in diffusion	diffusion requires material resources (Barnett et al., 2011; Sáenz-Royo et al., 2015)	financial resources	
	diffusion requires capacity resources (Njau et al., 2019; Rodriguez & Soeparwata, 2012)	knowledge	
	diffusion requires internal power resources (Dougherty & Hardy, 1996; Greenhalgh et al., 2004)	power	
The role of technology in organizations	technology matches organizations (Devadoss & Pan, 2007; Orlikowski & Gash, 1994)	match	
	technology brings benefits to organizations (Melville et al., 2004; Pishdad et al., 2012)	Perception of benefits	
The role of institutions in organizations	organizations' perception of the value of diffusion (Lin et al., 2020;		

	Meyer & Rowan, 1977)	
	diffusion is subject to artificial pressure (Abrahamson & Rosenkopf, 1997; Guler et al., 2002)	coercive pressures
	diffusion is subject to normative pressures (DiMaggio & Powell, 1983; Pasamar et al., 2023)	normative pressures

AST believes that diffusion behavior (including adoption and use) occurs due to three factors: the structural characteristics of the advanced itself, the internal system of the organization, and the influence of other external structural sources (tasks and organizational environment), among which the technological structure of advanced digitalization technology includes structural features and the spirits contained in the technology. The internal structure of an organization includes its own structural factors, such as organizational capabilities and resources, systems (such as reporting levels and standardized operational processes), and communication forms. The structural source factors in the external environment include competitive environment, relationships between related organizations, and government policies. The adoption behaviors corresponding to these three structural factors include complex structural factors, organizational endogenous factors and exogenous environmental factors. According to AST, the influencing factors of organizational adoption include. AST is a useful supplement to the theory of the duality of digitalization technology, providing a new research approach that considers the dual effects of organization and diffusion.

2.3.6 The concretization of AST in the study of organizational digital transformation

Based on the basic ideas of Structuration Theory, this study combines some variables of Technical Structuration Theory and AST to realize the research transfer of Structuration Theory in the diffusion of organizational digital transformation.

According to the Structuration Theory, “structure” does not refer to the analysis of the constituents of substances or organizations, but rather to the rules and resources that are repeatedly involved in social activities (Giddens, 1984). The rules and resources that make up the structure govern actions, and the consequences of actions change the status quo of rules and resources. Rules refer to the steps, processes, and guidelines for subjects to participate in social activities, and rules are composed of norms and meanings. Resources include allocative resources and authoritative resources, which are the basis and limitations of the actions of actors (Bryant & Jary, 2001). Allocative resources are the material basis of the actions of the adopters and represent human domination over nature; while authoritative resources are the social foundation for the actions of the adopters, which is the domination of people to people. If the subject has the necessary allocative resources for the actions of other agents, it can achieve authoritative resources. Therefore, from the perspective of the elements of structure, the diffusion of organizational digital transformation is essentially the structural changes of norms, allocative resources, and authoritative resources of adopters. Therefore, the analysis of the diffusion of organizational digital transformation should also be conducted in these three dimensions.

(1) Norms. The patterns followed by diffusion behavior are materialized within the organization as a means to provide public knowledge and protect the security of the subject across the time dimension, such as management system, organizational culture and behavioral process rules. The organization rejects self-worshipping norms through consistency and continuity across time and space for the consideration of maintaining its own security. While digital technology may be the creation of the subject outside the organization, it contains the technical characteristics and spirit of the creation subject with temporal consistency and continuity, that is, the structure of digital technology (Pearson & Keller, 2009). After the introduction of the digital structure into the adopting organization, it will be detached from the connection with the creator and appear in the action of the adopter. In order to avoid rejection and injury to itself, the organization should evaluate the compatibility between the two norms before adoption (Winston, 2018).

(2) Allocative resources. Material resources available for adopters, including the ability to control and transform material resources, are mainly embodied in the organization's financial resources. Therefore, for the diffusion of organizational digital transformation, whether the organization has sufficient and sustained financial resources is an important influencing factor. In addition, the utilization ability of various physical resources, especially the organization's management, use, and innovation ability of digital technology and digital systems, is also an important allocative resource (Verhoef et al., 2021).

(3) Authoritative resources. The ability of micro entities to control micro entities in organizational adoption activities, as well as the power to allocate allocative resources and authoritative resources within the organization. Authoritative resources are the integrators of organizational power, which are materialized as the attitudes of senior leaders. Therefore, in the diffusion of digital transformation, the support of senior leaders is equivalent to obtaining the necessary allocative resources and a portion of authoritative resources for adoption. Based on the above analysis, the organization has a need to protect its own security during the adoption process, and structural changes have generated a demand for the following three elements (Sunarso, 2024). As shown in Figure 2.1

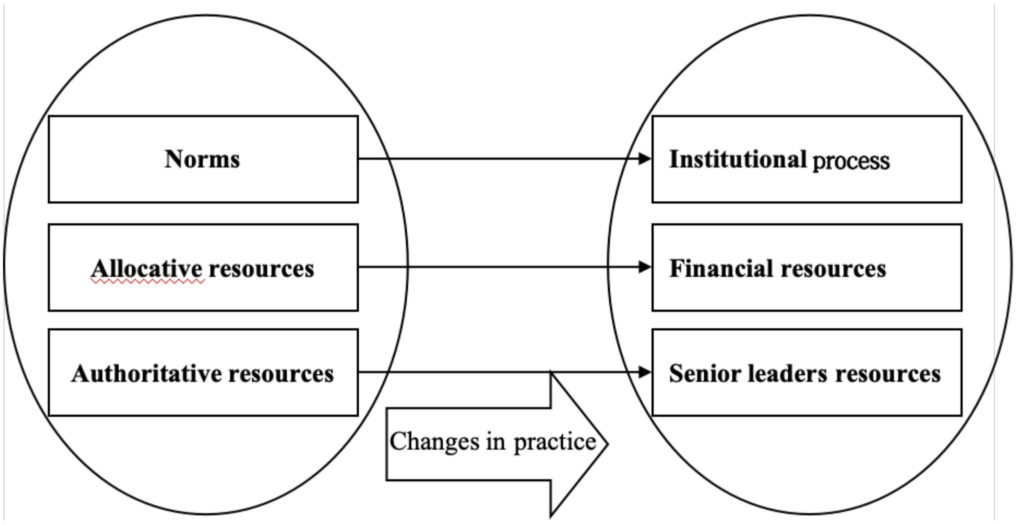

Figure 2.1 The change of structural factors in the diffusion of digital innovation

In the process of the diffusion of organizational digital innovation, both the adopted meso subjects (organizations) and micro subjects (individuals) are exposed to macro social norms. The ontology is consistent with the social environment for self-protection needs. Therefore, the adopters are influenced by various social structures and transform social norms into self-norms. This normative transformation is achieved through system integration and social integration. Diffusion is not simply the self-realization of an organization, and no organization can fully independently achieve adoption. Diffusion and its effects inevitably generate activities with social norms, namely social integration and system integration. Therefore, the analysis of diffusion also needs to be analyzed from two dimensions (Ramotar, 2016).

Social integration refers to the interaction that must occur in the presence of practical participants, which is entirely the behavioral interaction between human active subjects, emphasizing the promotion of a certain activity by human factors (Kowsikka & James, 2019). System integration refers to the interaction that does not require the presence of all practical participants and can occur in the absence of some subjects. The receiver consciously and spontaneously adopts structural digitalization to form self-regulation, while the interaction process affects the agent's lack of proactive behavior, similar to normative pressures in institutional theory or social environmental factors in contingency theory. System integration may have unclear or missing subjects, but the influence of subjects can transcend time and space limitations, such as cultural traditions and social customs. Digital transformation has become a social consensus and development trend for organizational adoption. It is difficult to prove who led the wave of digitalization, but it does indeed affect organizational decision-making. From a comprehensive analysis, the factors that affect organizational adoption include social integration (driven by human factors), system integration (normative assimilation), matching degree (normative consistency), allocative resources (financial resources), and authoritative resources (high-level attitudes).

From the perspective of individual rational behavior, the influencing factors of diffusion focus more on endogenous structural factors of the organization and ignore environmental normative factors, while the perspective of institutional theory focuses on environmental factors and ignores internal factors (Egbe et al., 2018). On the one hand, AST focuses on the complexity and openness of technology, as well as the impact of these technologies on the organizational adoption process and the adjustment of organizational processes and institutional structures. On the other hand, the allocative resources, authoritative resources, and capabilities of an organization will also affect the degree of diffusion acceptance. AST provides an analytical framework for related research. Therefore, this study uses the overlapping factors of AST and other theories as the theoretical basis, through the analysis of institutional theory, innovation diffusion theory, and complex adaptive system theory, and by integrating similar or overlapping variables, the following variables from the three dimensions are proposed as the key elements to be focused on in the subsequent research interview. As shown in Table 2.6.

Table 2.6 Influencing factors

	Influencing factors	Institutional theory	Innovation diffusion theory	CAS Theory
Environmental factors	competitive pressures	√		
	coercive normative pressures	√		
	trend pressures	√		
	government policies			√
Technical factors	technology-task match		√	√
	technology-organizational compatibility		√	√
Organizational factors	executives’ attitudes		√	√
	digital knowledge stock		√	√
	Digitalization resource readiness		√	√
	organizational communication		√	√

2.4 Complex adaptive system (CAS) theory

2.4.1 Adaptability creates complexity

Complexity science is known as “the science of the 21st century” and is a hot topic in the academic field. It was not until 1994 that John H. Holland proposed a brand-new scientific theory, CAS theory (Hill, 2011), and tried to explain complex systems in various fields with it, which quickly attracted the attention of the academic community. As one of the three main stages of complexity science research, the CAS theory keeps the change of thinking mode brought by complexity science on the one hand and highlights the discussion of complexity from the aspect of adaptability on the other. Therefore, the researches in this filed beyond China can also be summarized from these two aspects. In terms of the research on the change of thinking mode, many works related to complexity can be said to describe the ideological understanding (Holland, 1996, 1998; Kelly, 2015) and principles of law (Esley & Kleinberg, 2011; Fishwick, 2004; X. Liu et al., 2017) related to complex systems from different subjects and perspectives. Although only some of these works explicitly discuss issues related to the CAS theory, just as there is a close relationship between adaptability and complexity, those studies that simply discuss complexity (Mitchell, 2009; Thompson & Stewart, 2002) are more or less involve adaptability, as shown in Figure 2.2.

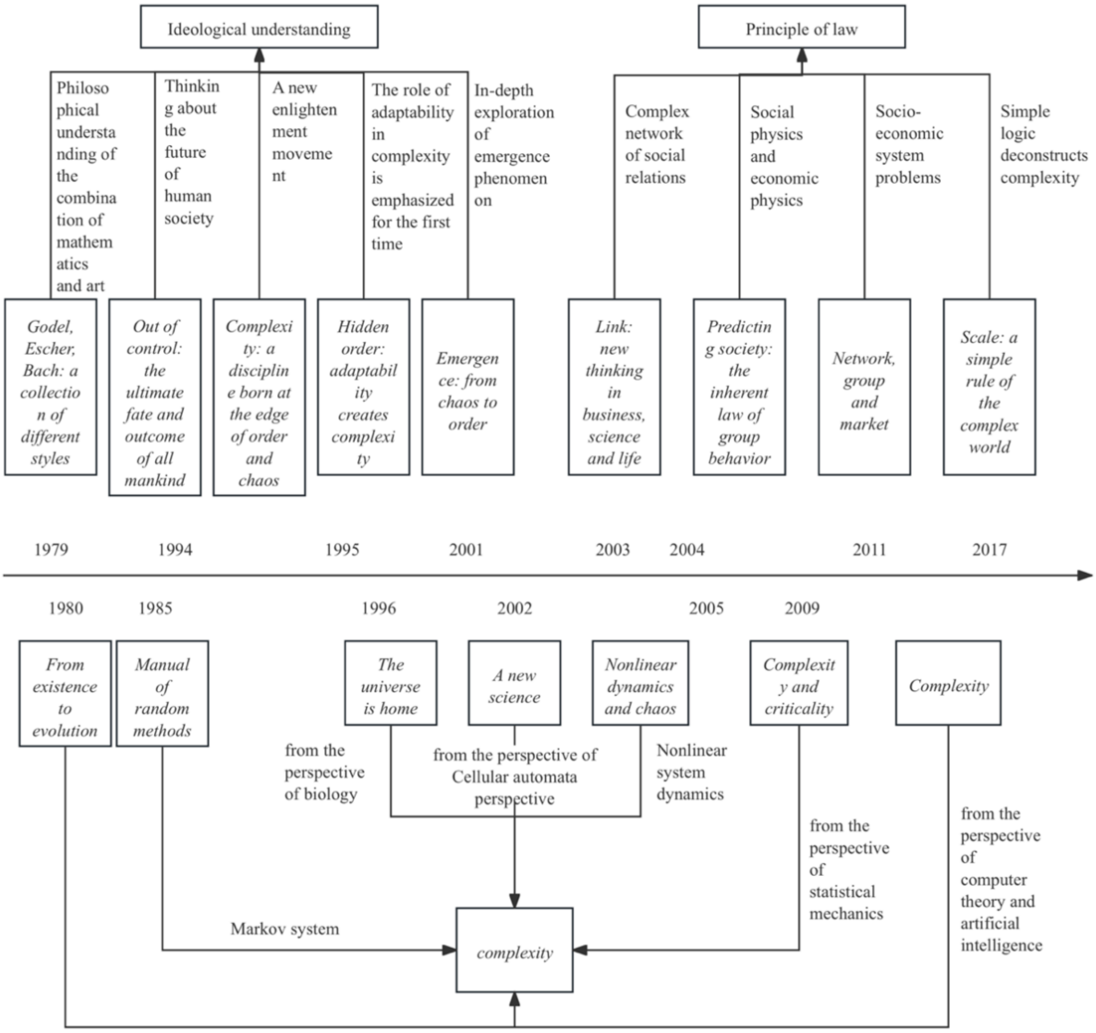

Figure 2.2 The adaptive characteristics

In terms of adaptive characteristics, studies beyond China mainly focus on the application of CAS theory in different scientific fields. Since the concept of adaptive agent was born out of living organisms, the theory was first used in life and physical sciences, and then gradually extended to management, sociology and other studies to solve practical problems of CAS. For example, in the field of management, scholars focus on the interactive management of organizations with the help of CAS (DeRosa & McCaughin, 2007; Warfield, 1999), knowledge innovation management (Buijs, 2003) and simulation with models (Small, 2005). In the field of sociology, scholars have studied different types of complex networks (Jr & Monteiro, 2022) and the emergence simulation of different relationships (Chiles et al., 2004) by using CAS to describe the flow nodes and network relationships of adaptive agents in complex adaptive systems. CAS is a new methodology, which explains the internal operation rules of complex systems, such as the evolution, development and cooperation. CAS theory regards the constituent units of the system as active agents with their own purpose and initiative. The system agents have their own purpose and initiative with strong adaptability and can communicate with the environment and other agents. Additionally, they will constantly learn and accumulate experience according to the learned experience and change their own structure and behavior to produce adaptive living states and development strategies, which promotes the continuous evolution of complex systems towards stability (Ross, 2010). At the same time, it clarifies the internal logic of complex systems, and effectively provides a theoretical basis for people to understand, control and manage complex systems.

That adaptability creates complexity is the core idea of CAS theory, whose most basic concept is adaptive agent (hereinafter referred to as agent). Different from the elements, parts and other concepts in traditional systems theory, the agent is a new, living, active and adaptable new concept. It can not only study and progress independently on the micro level, but also interact with the external environment on the macro level. Therefore, it is a giant step forward to introduce the concept of agent in CAS theory (Y. F. Liu, 2014).

Based on the concept of agent, Holland proposed seven concepts common to CAS: aggregation, nonlinearity, flow, diversity, identification, internal model, and building blocks. The first four are individual characteristics that play a role in the process of learning and evolution, while the last three are mechanisms that interact with the environment (Tan & Deng, 2001). The specific definition is as follows: 1) Aggregation: the combination of individuals to form a new larger entity. This “larger” is not about the size in the traditional sense, but about the aggregation of structure and connotation. 2) Nonlinearity: There is not just a simple linear relationship in the process of individual development, especially in the repeated interaction with the system. 3) Flow: There is a flow of material resources, energy and digitalization between individuals and the environment, and between individuals. Whether the flow is smooth and how fast the turnover is will directly affect the process of the system. 4) Diversity: In the operation process of the system, the development of individuals is not independently. There will be wider gaps and greater differences with the development of the individuals, leading to a variety of diverse individuals. 5) Identification: It is very important, aiming to help the agent choose and identify digitalization. 6) Internal model: Different individuals have different complex internal mechanisms, which are unique survival and reaction mechanisms of individuals. 7) Building blocks: Complex systems are not only composed of individuals and environments, but also composed of other structures that support the operation of the system. The main characteristics of CAS are: self-organization of subsystems, self-adaptability of agents, cooperative progress of multi-agents, rapid equilibrium of systems, and overall evolution of systems (Lindstrom, 2003).

The core idea of CAS is that adaptability creates complexity. It can be understood that the “adaptability” of the agent creates the “complexity” of the system. Based on the theory, the adaptability of the agent is to adjust its own behavior according to the environmental digitalization. It is the interaction of agents that improves the survivability of the whole system. The adaptive behavior of agents is the inner driving force of the evolution of complex adaptive systems.

(1) The basic unit of CAS is the adaptive agent. The agent has initiative, which, in the process of system evolution, constantly interacts with the surrounding environment, accumulates experience through the feedback of its own behavior results, modifies its own behavior rules, and seeks its own maximum adaptability. The agent has the ability to learn, and its learning process is from weak to strong, from simple to complex. Within the agent, cognitive patterns exist in a variety of ways and can be changed by random or conscious behavior. They can also update themselves to achieve survival of the fittest in the process of choose-make-retain.

(2) The adaptability of an agent is the result of a complex combination of local and systemic factors. There is no simple causal relationship, but an active adaptive relationship in the interaction between two agents, and between the agent and the environment. The agent who cannot adapt to the environment will actively change the way of behavior, and evaluation basis is the maximum adaptive ability of the agent, that is, local optimization. This is the source of differentiation and diversity in CAS. When the behavior changes, the agent usually becomes more robust and reliable, and thus adapting to more stringent environmental conditions.

(3) The constant digitalization exchange between agents and the environment is a prerequisite for the evolution of CAS. Agents in the CAS receive and respond to environmental digitalization in parallel. There is an identification mechanism of agents that can select interaction objects specifically for interaction behavior to promote the aggregation phenomenon of different agents and produce diverse agent aggregates. This is conducive to the distribution and specialization of system intelligence, and finally new traits and attributes emerge from the bottom up at the macro system level.

(4) CAS is dynamic. Since the external environment changes constantly, the agent will always be in a state of real-time change in order to improve its survival ability. Even if it is in a state of equilibrium, it is only in dynamic equilibrium. When any relationship in the system changes, the system will re-find a new dynamic equilibrium point to maintain its own survival and development. The dynamic equilibrium of CAS is affected by the number of agents, the rules of behavior and their interactions, so it is of practical significance to study the robustness of the system.

(5) CAS has self-organization. The CAS does not have a unified control center, because it does not have a unified command center to coordinate arrangements. The nonlinear interaction between agents leads to the creation of new characteristics or structures, that is, emergence occurs.

(6) CAS has multiple levels. The agent in the system can produce the main aggregate through the identification function of the mark, and the aggregate can also produce a larger aggregate through the aggregation effect, which results in the multi-level of the CAS. And the lower level is the component of the higher level. It can be seen that the smaller system can be attached to the higher system through the aggregation effect.

(7) CAS emphasizes local optimization. The agents in complex adaptive systems tend to pursue local optimization. Each adaptive agent improves its own adaptability and survival ability to formulate interaction rules. In a CAS, the decision and behavior of the current agent depend on those of other agents.

2.4.2 Adaptability is the key to solving complex problems

In discussing the cross-disciplinary application of CAS theory, Holland once pointed out that different CAS shows different advantageous attributes, so the ideas should come from different CAS in different disciplines. Based on this, this study further distinguishes the relationship between complexity and complex problems and finds that adaptability is the key to solving complex problems. Thus, it is clear that the research problem of this study should center on adaptability.

(1) Complexity is the inherent property of the system. According to Holland’s theory, for CAS, adaptability creates complexity. The systems are in different environments and form different complexity in adaptation with different agents. (Holland, 1996).Complexity is the embodiment of the vitality of CAS, a property enabling the realization of system emergence and the self-organization evolution, and it is also the necessary stage for the system to move to the edge of chaos. It cannot be determined by cybernetics, and it is an inherent property of the system that cannot be directly observed. In addition, complexity cannot be solved or eliminated, which is equivalent to denying the essential connotation of CAS.

(2) Complex problems are the external manifestation of the system. Complex problems are caused by the complexity of the system and is the external manifestation of the complexity of the system. “Problems” here are actually neutral words. In other words, not all complex problems in the system need to be solved or corrected, and it is impossible to solve all complex problems among various nested systems. This is also the reason why scientists in various fields, no matter how they cooperate, focus on solving complex problems within their own disciplines. Therefore, what we’re trying to solve is only a subset of complex problems, a local manifestation of the complexity of the system. As the local complexity improves, the system continues to adapt and evolve into new complex problems and retain their complexity repeatedly. (Holland, 1996).

(3) Adaptability is the key to solving complex problems. Based on the analysis of system adaptability, complexity and complex problems, it can be seen that adaptability can produce the complexity that leads to the old complex problems, but it is also the key to adapting to changes and promote the system evolution to the new emergence state, which also means the disappearance of the old emergence (farewell to the old complex problems). This disappearance involves the solution or correction of local complex problems. Therefore, the relationship can be made clear as follows: The local complex problem is the result of the interaction of agents in the previous system stage, and the complex problem is caused by the complexity resulted from insufficient or improper adaptability. Increasing or adjusting adaptability is an effective way to solve the local complex problem. Therefore, it is necessary to improve local adaptability of specific complex problems. (Holland, 1996).

2.4.3 Taking adaptability as the core

2.4.3.1 Develop complex understanding around the adaptive agent

Complex understanding includes a comprehensive understanding of the adaptive agent and the CAS in which it resides. The basic characteristics described by the adaptive agent are analyzed above. Therefore, this part will further discuss the characteristics of the agent, behavior rules and system situation based on the basic characteristics described by the adaptive agent.

2.4.3.2 Characteristics of adaptive agents

(1) Initiative

Take ant colonies and other CAS in nature as an example. The perception and effect ability of adaptive agents is the root of ensuring their survival and continuation of their own interests in adapting to complex situations. This feature illustrates two key issues: First, the ability of adaptive agents is not given by the CAS but derived from its survival instinct, which is the embodiment of initiative; Second, the ability is the basic motivation of the CAS (Carmichael & Hadžikadić, 2019).

(2) Autonomy

As a living organism, adaptive agents have the ability to choose for themselves the degree and path of interaction. Autonomy and initiative are in the same line but have different focuses. Autonomy emphasizes the law of the agent's behavior from the inside out, while initiative is more general.(Vernon et al., 2015)

(3) Sociality

The social adaptive agent is composed of a number of components, that is, different adaptive agents have the same components to a certain extent, which is its social basis at the micro level. At the same time, in the process of interacting with other adaptive agents, the solidified internal model absorbs external digitalization locally, while the selective interaction interacts with each other in mutually identifiable language, which is the sociality of adaptive agents at the macro level. The sociality enables researchers to study the adaptive agents on a broader level (Silver et al., 2021).

(4) Irritability

In the biological world, irritability is the simplest and most direct response of organisms to complex situations. Holland used frog predation as an example to explain the stress process of adaptive agents. It is worth pointing out that the content of stress behavior and the time of stress reaction of the adaptive agent are different. Even when facing the same situation, the adaptive agent in different periods may make different stress responses. This is also one of the reasons why the system is dynamic and constant (Leibenluft, 2017).

2.4.3.3 Analysis of CAS

(1) The core composition of the system -- adaptive agents

Holland pointed out that it is the interacting adaptive agents that make up the CAS. There are many reasons for the system complexity. The CAS is the result of examining the complex system from the perspective of adaptation. Therefore, CAS is a special complex system centered on adaptability, and the adaptive agent is its core component. It should be emphasized that the adaptive agent is not simple combination but interacts with each other in many aspects. Therefore, it cannot be fully interpreted by traditional reductionism, and the deconstruction of the system needs to be based on the combination of holism and reductionism (Holland, 1992).

(2) System operation mode -- Combination of macro agents and micro system

When it comes to adaptive agents and their interactions, the CAS theory points out that CAS involve the survival of micro-agents and the development of macro-systems. The two are intertwined, and the adaptive agents are the link between the macro agents and micro system. Therefore, the adaptive process of the agent is not only a process of improving its own adaptive ability, but also a process of optimizing the system's adaptive ability. The macro and micro combination of the adaptive subject is the unique operation mode of the CAS (Carmichael & Hadžikadić, 2019).

2.4.4 Co-evolution of adaptive agents and systems

Co-evolution is not only a description of the self-organization of the whole CAS, but also a manifestation of the vitality of adaptive agents. It is the key to the survival of the agent and the system in which it resides. Co-evolution makes the CAS tend to the edge of chaos, and emergence occurs in the special dynamic equilibrium zone. It reveals the characteristic that the CAS cannot be controlled but can only be guided (Fischer-Kowalski & Rotmans, 2009).

2.4.4.1 The connotation of evolution -- agent survival and system development

The interaction of adaptive agents in CAS essentially leads to two kinds of results, adaptation or inadaptation. From the perspective of the system, in the face of the interaction of adaptive agents driven by instinct, the system gives feedback in different situations where positive feedback is adaptation, while negative feedback is inadaptation. In the long-term interaction, the positive feedback is constantly retained, with the help of which the adaptive agent evolves itself, thus bringing the opportunity to change itself and strengthen its survival ability. This process occurs in all the adaptive agents in the system, so the evolution process of each adaptive agent becomes the systematic feedback of other adaptive agents. In co-evolution process of multiple agents, the system can develop. The connotation of evolution illustrates two things: First, the adaptive agent cannot complete the evolution just by itself, but needs the system to give positive feedback; Second, the feedback of the system is the reference criterion for the evolution goal of the adaptive agent (Furneaux et al., 2008).

2.4.4.2 Evolution results -- chaos edge

In his book *Complexity*, Michel Waldrop (2019) gave a profound interpretation to the edge of chaos. He vividly described the balance point between order and chaos by taking life and thought as examples. It can be seen that the abstractness and extensity of the chaos edge is not a line or surface of the junction, or a point of equilibrium presented by the edge. The co-evolution of adaptive agents and systems is a phenomenon that always exists in the long-term development of CAS. In the cyclic interaction, the evolutionary result itself is dynamic and constant. Therefore, the chaotic edge is not only the description of the critical state, but also the evolutionary result produced by the adaptive agents in the co-evolution process with the system at any time cross section. Besides, each evolutionary result is the foundation of the next evolution.

2.4.4.3 Evolutionary manifestation – emergence

Emergence occurs in CAS in the special boundary of chaotic edge guided by evolution, so emergence is the external manifestation of the evolution of adaptive agents. Besides, emergence is also one of the features that distinguish CAS from other systems. Emergence is not a simple combination of adaptive agents, but a phenomenon in the combination of micro agents and the macro system. It is a systematic phenomenon that cannot be taken into account when only considering the adaptive agents themselves without considering their interaction in the system. In his book *Emergence*, Holland (1998) introduced the emergence caused by weight change. According to the evolution process of adaptive agents, it can be seen that weight change is the behavior of adaptive agents to adjust their own adaptation after receiving feedback from the system in the interaction process. Therefore, emergence reflects the evolutionary stage results. It is the manifestation of different results of adaptive agents in different situations under the same law, and it is a dynamic phenomenon caused by the co-evolution of adaptive agents and systems.

2.4.4.4 Focus on multiple adaptations inside and outside adaptive agents

Based on the CAS theory, it can be deduced that the complexity of CAS comes from multiple internal and external adaptations of the agent. In addition, the connotation of ideas can be further interpreted through specific interactions, as shown in Figure 2.3.

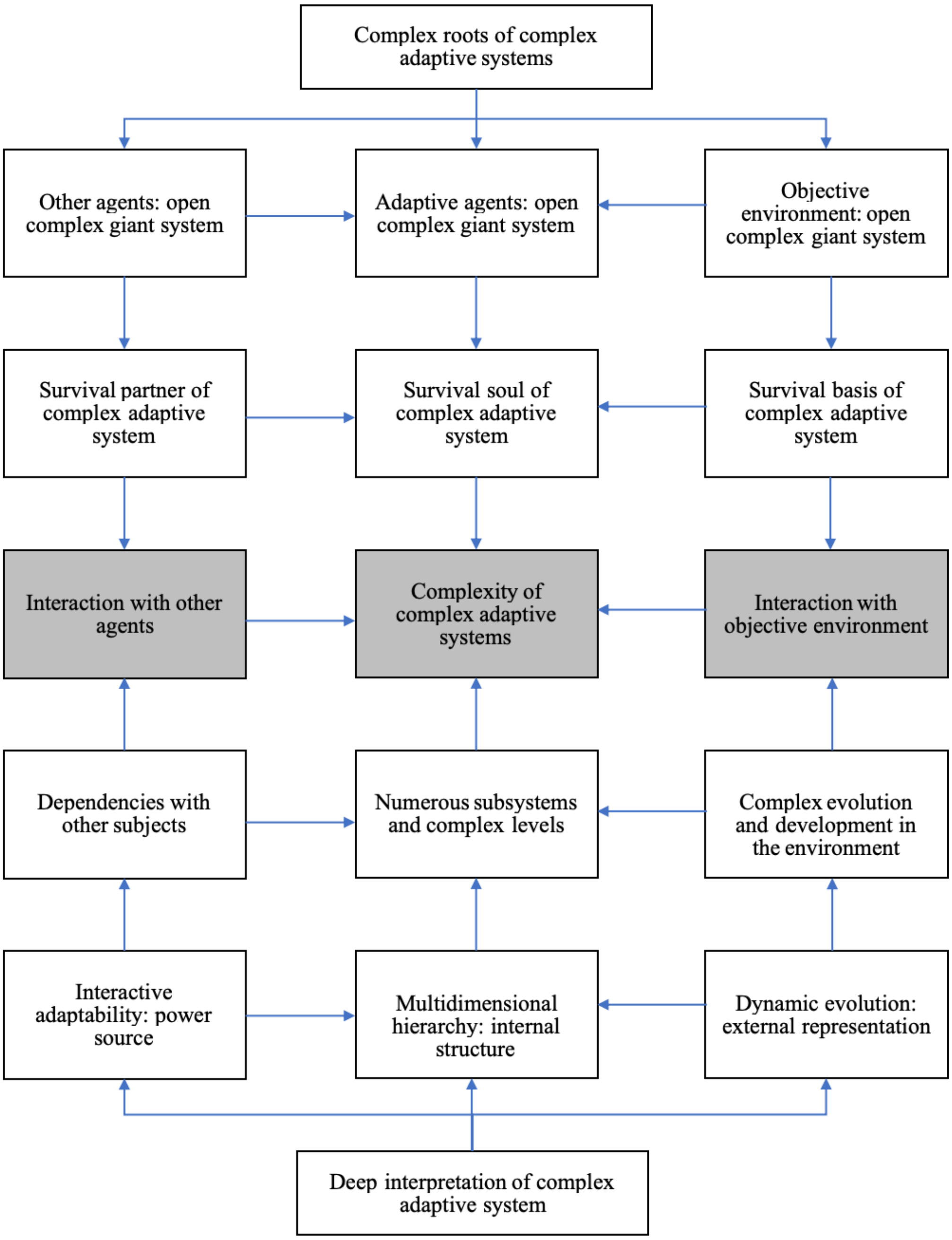

Figure 2.3 Profound analysis of the connotation of complex adaptive system theory

2.4.4.5 Internal adaptation of the agent - emphasizing its own participation in learning

The adaptive agent itself is also an open and complex giant system, as well as the core of the CAS. Besides, it is the adaptive agent that endows the CAS with self-awareness. However, the adaptive agent itself is also the existence of many subsystems and complex levels, which is only manifested in the form of a whole when interacting with other agents. Therefore, the multidimensional level of the adaptive agent itself is the internal structure of the CAS. The self-dimension of the agent emphasizes the adjustment adaptation within the agent, which is a participatory learning process for the agent to achieve active development. This link plays a basic internal role in the system, and the subject conducts internal organizational behavior (D. Zhou et al., 2024).

2.4.4.6 External adaptation of the agent -- emphasizing the interaction between agents

The adaptive agent does not exist in isolation but interacts with other agents more or less, and the other agents themselves are complex giant systems (Holland, 1998). For the adaptive agent, these agents are its survival partners, depend on which the adaptive agent can survive through interaction. Therefore, the interactive adaptability between adaptive agents and other agents is the power source of the system. The inter-agent dimension emphasizes the agglomeration adaptation between agents, which is the communication and interaction process of the agents to realize value-added development. This link plays a driving role in the system, and the agents carry out external reaction behaviors.

Therefore, the focus should not only be on the productivity or stability of the system, but also on its adaptability. The same is true for digital transformation in hospitals. To fundamentally improve the diffusion of digital systems in hospitals, it is necessary to adjust their own healing capacity in the system. We should not simply improve its service conditions but build a spatial adaptability agent serving patients from a more systematic perspective.

2.4.4.7 External adaptation of the agent -- emphasizing the retention of feedback between the agent and the environment

The CAS theory regards the adaptability of agents as the basis of the overall evolution of the system, and the objective environment also plays an important role in the CAS. It can be said that the environment is the survival basis of the system(Holland, 1998). All kinds of flow exchange such as material flow and digitalization flow of the system need to be completed in the objective environment, which is itself an open and complex giant system. The adaptive agent not only interacts with the objective environment, but also manifests the results of its complex evolution in the objective environment. Therefore, the dynamic evolution of the adaptive agent in the objective environment is the external representation of the CAS. The agent and environment dimension emphasizes the mutual feedback adaptation between the two, which is the feedback and persistence process of the agent to realize the evolution and development. In the process, the agent adjusts behavior, forming the multi-level emergence of multi-agent participation in the environment of the CAS.

2.4.4.8 Correlation analysis between hospital station domain space and adaptive agent

With the popularization of CAS theory, there are many tool platforms for multi-agent simulation modeling, such as Netlogo, Mason, Repast, Swarm, Ascape. Among them, Netlogo platform interface simple text editing function is powerful. The platform is mostly used in the

2.4.5 Research progress of CAS theory in health field

In the late 1990s, CAS theory gradually began to be applied in social science research, and it is a new theory in the health field. The development of human society is also the result of self-adaptation of complex systems (Chaffee & McNeill, 2007). Management is still relatively backward from theory to practice. The traditional linear thinking and causal inference specific to the health research cannot accurately and completely express the behavioral laws of the system, and such research thinking is often constrained by systematic observation, ignoring the adaptation, coordination and feedback behaviors of the internal agents in the system (Brown, 2006). The active adaptation and adjustment behavior of these agents has become a problem that today's medical service system needs to face. According to the CAS theory, the system is a self-organizing system composed of multiple interacting sub-systems. The whole system is an organism that can constantly adjust itself according to environmental changes, so the evolutionary power of the system is generated by the active adaptation of the agent to the environment (Penprase & Norris, 2005). In addition, linear and non-linear effects abound in health systems. Therefore, the CAS theory is regarded by scholars as a scientific method to understand the complexity of health system (C. M. Martin & Sturmberg, 2005).

To sum up, the application of CAS theory in the health field mainly focuses on six themes, namely, research on complex collaborative agents of health system, research on the complexity of health system, application of CAS theory in medical education and training, health consultation service system, tele-mobile health service system and universal health coverage. However, there is little research on the diffusion of digital transformation and innovation in the academic circle, especially the lack of specific behavioral analysis on the interaction between the agents and the environment, and between agents. Therefore, from the perspective of comprehensive governance, we regard the health system as a complex system, and managers should pay more attention to the interaction modes and processes within or among institutions (Patel et al., 2008). The complexity of the health system lies in the "multi-level, multi-factor and multi-system" of the management objects and the "variability" of the management methods.

Therefore, it is urgent to use the CAS theory to provide a new understanding for China's health system, which not only deduces the evolution process of CAS, but also builds a strong coupling cooperation network within the system (Sargeant, 2009).

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Chapter 3: Methodology

3.1 Research method

3.1.1 Method

(1) Literature research

Literature research is mainly a review and analysis of related theories and existing literature. The connotation, characteristics and application of Complex Adaptive Systems Theory were reviewed through domestic and international literature. Theoretically, the theory lays the foundations for the research on the division, stages and characteristics of maturity. Meanwhile, the policies and literature related to digital transformation were sorted out to analyze the dynamic capabilities, factors, barriers and consequences of hospital transformation. Finally, the literature on domestic and international systematic research was summarized to sort out the methods for research such as diffusion paths and maturity (X. Y. Liu et al., 2025). For literature search, Chinese academic databases such as CNKI, VIP, and Wanfang Database are selected, while foreign language databases include Web of Science, PubMed, and BMJ. Moreover, reports and policy updates on the practices and experiences of medical service systems are gathered from websites of the World Health Organization and the National Health Commission of China.

(2) On-site research

Open-ended and semi-structured interview was applied to pediatrics with different levels of maturity in implementing digital transformation, to understand critical mechanisms of the transformation, the role of policy in facilitating the transformation, and to analyze the basic conditions and key links of the implementation (J. Sun et al., 2024). Interviews were conducted with policy makers, healthcare service providers, IT personnel, and patients. The interviews mainly cover the following areas: the effect, behavioral changes, and key mechanisms of digital transformation, and patients' attitudes towards digital transformation, as well as the resistance to achieve it.

On-site data collection. Empirical data was obtained from the pediatrics of Six hospitals in the Pearl River Delta, namely, Nanfang Hospital, Guangzhou United Family Healthcare, Shenzhen Nanshan District People's Hospital, and Guangdong Maternal and Child Health

Hospital. The social factors survey examines aspects such as population distribution, income levels, the efficiency of health resource use, and the equitable distribution of health resources. The survey on government administrators mainly examines policy design, resource allocation, management forms, staffing, financial allocations, supervision and management. The survey on healthcare institutions primarily focuses on the service capacity, revenue and expenditure ratio, staff composition, income of medical workers, as well as interest demand of healthcare institutions at all levels. The survey on medical service receivers is primarily about the income level, the services received, cognition of medical institutions, and the costs. The survey on medical insurance providers mainly investigates payment policies of medical insurance, reimbursement rate and others.

(3) Case study framework

This study employs a multiple-case study approach, focusing on the digital transformation practices of six pediatric hospitals in the Pearl River Delta. Through the deep interaction between a three-dimensional theoretical framework and empirical observations, interviews are mapped to the theoretical framework:

Institutional Theory focuses on the impact of policy pressures (such as electronic medical record (EMR) grading) and organizational legitimacy (such as JCI accreditation) on transformation pathways (G. F. Wang et al., 2018). For example, Public Hospital H2 achieved EMR Level 7 certification through the "policy compliance + research-driven" pathway, with its structured data capabilities meeting the needs of national-level research projects.

Innovation Diffusion Theory analyzes differences in technology adoption characteristics (such as relative advantage and compatibility) (Rogers, 1962). For instance, Private Hospital H3 enhances the medical experience for international patients through "personalized services + AI models," with its closed-loop privacy protection system compatible with international insurance standards.

Complex Adaptive Systems (CAS) Theory examines system dynamics and agent interactions (such as cross-departmental collaboration) (Holland, 2006). For example, Hospital H1 relies on "cross-departmental agile teams + regional economic resources" to achieve rapid iteration of AI-assisted diagnostic technologies, reflecting the dynamic balance between "needs and technology."

Through case studies, this research constructs a "Dynamic Balance Model," breaking through the limitations of single theories (Eisenhardt, 1989). For example, H2 achieves a balance between policy compliance and technological innovation by synergizing institutional pressures (grading requirements) with research needs and leveraging the CAS "trial-and-error feedback" mechanism. The study forms a closed loop of "theoretical guidance → case-driven theory iteration." By expanding theoretical boundaries based on the unique characteristics of pediatric settings (such as patient age structure), concepts such as "adaptive thresholds" and "dynamic balance" are proposed, providing methodological references for digitalization research in healthcare.

(4) Comparative study method

The thesis concretizes abstract problems through a comparative research method. Specifically, it includes comparative research at two levels. One is a horizontal comparative study among pediatrics in Six hospitals, and the other is a comparative study of the characteristics of hospitals in different cities, of different types and at different levels. It is expected that through the comparative study, common and individual problems will be found, so as to provide a realistic basis for in-depth research.

(5) Three-level coding

This study uses the Three-level coding to explore the differences in pediatric digital maturity. Six healthcare institutions of different types are selected through purposive sampling. Data is collected from semi-structured interviews, policy documents, and system operation logs, and analyzed through three-level coding. First, open coding extracts initial concepts to form 72 categories: "technological adoption drivers, resource constraint mechanisms, and institutional adaptation processes." Then, axial coding constructs subcategories such as "demand response under policy guidance, departmental capacity thresholds, and digital divide reinforcement effects." Finally, selective coding develops the "Dynamic balance Theory Model of Pediatric Digital Maturity Differences" which reveals the dynamic coupling mechanism among institutional environment, organizational habitus, and technological ecology, offering a theoretical framework to explain regional differences in pediatric digital transformation.

(6) Qualitative Comparative Analysis (fsQCA)

The digital transformation of pediatrics is a systematic project influenced by multiple interrelated factors. Traditional empirical methods tend to focus on examining the net effects of individual factors while neglecting integrated effects, making it difficult to comprehensively and deeply explore the pathways of pediatric digital transformation (Vesoulis et al., 2023). The fuzzy-set Qualitative Comparative Analysis (fsQCA) method allows investigation into new market relationships formed by multiple antecedent conditions, which imply more interactions and stronger connections, as well as the impact of different pathways adopted by governments on outcomes, thereby effectively elucidating the complex causal relationships underlying the phenomena. Based on this, following three-level coding, this study defines the seven categories of axial coding as first-level antecedent variables to explore the key factors contributing to maturity differences and the configurational pathways involved.

3.1.2 Use theory and method to conduct empirical research

The previous literature review includes one definition: digital transformation, four theories:

Systems theory (mainly focuses on processes, factors); Diffusion of innovation (mainly focuses on processes, factors, moderating variables); Organizational theory (mainly focuses on processes, factors, moderating variables); Maturity (mainly focuses on processes, factors, moderating variables).

So, the research put their summary in a table with columns for factors, process outcomes, moderating variables, and rows for big theories, as illustrated below in Table 3.1.

Table 3.1 Digital research framework of hospital pediatrics

Aspects		Hospital digital transformation	Innovation diffusion theory	Institutional theory	AST /CAS
Factors	Environmental	Hospital system, Digital infrastructure, Hospital culture	Artificial pressure, standard pressure, market conditions, policy environment, medical service environment	Institutional pressure, background uncertainty	Competitive pressure, forced gauge pressure, tidal current pressure, government policy
	Resource	Input of material resources, capital investment	Technical resources, knowledge reserve	—	Digital knowledge reserve, Digitation resource readiness
	Innovation	Digital technology, digital Knowledge	Relative advantage, compatibility, complexity, result demonstrability, visibility	Institutional demand, institutional diversity, organization objective	Technical-task fitness, technical organization compatibility
Process		Explore-construct -extend (digitalization-digitization-intelligentize)	Inception – adoption – adaptation – diffusion – infusion	Contradiction-interaction-decision- transmutation	Implement-interaction-coordinate-feedback-evolution
Outcomes		Hospital pediatric digital transformation maturity	Diffusion of digital transformation innovation in hospital pediatrics	Transformation new institution	Hospital pediatric digital transformation
Moderators1		Hospital location, scale, passenger flow, patient demand	Organizational promotion, organizational acceptance, management-driven, organization size, organization types	External policy change, conflict of interest distribution	—
Moderators2		Digital talent, digital governance	Communication channel, emergence of new technology, incentive mechanism, perceived usefulness and perceived ease of use	—	—

Explanation of the Table: A Theoretical Framework for Hospital Digital Transformation.

The table presented in this study serves as a comprehensive framework for analyzing the digital transformation of hospitals, with a particular focus on pediatric units. It integrates theoretical perspectives from Institutional Theory, Innovation Diffusion Theory, and the Maturity Model to provide a multi-dimensional understanding of the transformation process. This framework is designed to bridge the gap between theoretical constructs and empirical observations, offering a structured approach to identifying key factors, processes, outcomes, and moderating variables that influence digital transformation in healthcare settings.

Structure of the Table. The table is divided into two main sections. The first section provides examples of digital transformation within hospitals, highlighting specific roles and concepts relevant to the transformation process. This section serves as a practical illustration of the phenomena under investigation, grounding the theoretical discussion in real-world scenarios.

The second section of the table is dedicated to exploring how three key theories—Institutional Theory, Innovation Diffusion Theory, and the Maturity Model—can elucidate various aspects of the digital transformation process. This section is organized into columns, each representing one of the three theories, and rows that correspond to different dimensions of the transformation, such as environmental factors, resources, technology, processes, outcomes, and moderating variables.

Theoretical Integration. Institutional Theory provides a lens through which to examine the environmental factors influencing hospital digital transformation. This theory emphasizes the role of external institutional pressures, such as government policies and regulatory frameworks, in shaping organizational behavior. In the context of healthcare, hospitals are often subject to centralized governmental policies and medical reform initiatives that mandate or incentivize digital transformation. These policies can act as both carrots (incentives) and sticks (penalties), compelling hospitals to adopt new technologies and practices. Institutional Theory also highlights the importance of developing responsive strategies to navigate these policy environments, whether through proactive innovation or more passive compliance.

Innovation Diffusion Theory offers insights into the characteristics of innovations that facilitate or hinder their adoption within healthcare organizations. Key factors include the relative advantage of the new technology over existing solutions, its compatibility with existing organizational routines and culture, the complexity of implementation, observability of results, and the visibility of the innovation within the organization. For instance, digital technologies that offer clear benefits in terms of efficiency, quality of care, and patient convenience are more likely to be adopted. The theory also underscores the importance of the diffusion process, which involves the stages of inception, adoption, adaptation, and institutionalization of the innovation within the organization.

The Maturity Model provides a framework for assessing the stages of digital transformation and the maturity levels achieved by hospitals. This model typically includes stages such as initiation, adoption, adaptation, and diffusion, with each stage representing a different level of sophistication in the use of digital technologies. The maturity model helps to identify the challenges and opportunities at each stage, guiding hospitals through a structured transformation process that ultimately leads to the institutionalization of digital practices.

Factors, Processes, Outcomes, and Moderators. The table identifies several key dimensions of hospital digital transformation:

1. Factors: These include environmental factors (e.g., policy environment, regulatory requirements), resource factors (e.g., availability of technology, human resources), and technological factors (e.g., compatibility, complexity). These factors are analyzed through the lenses of Institutional Theory and Innovation Diffusion Theory to understand their impact on the transformation process.

2. Processes: The processes involved in digital transformation are examined through the stages outlined by the Maturity Model. These processes act as mediators between the influencing factors and the outcomes, reflecting how hospitals respond to external pressures and internal capabilities to implement and adapt to new technologies.

3. Outcomes: The outcomes of digital transformation are assessed in terms of operational efficiency, service quality, patient satisfaction, and other relevant metrics. These outcomes are evaluated using both Institutional Theory and Innovation Diffusion Theory to determine the effectiveness of the transformation efforts.

4. Moderators: The table also considers potential moderating variables that may influence the relationships between factors, processes, and outcomes. These variables include hospital characteristics such as geographical location, size, and type, which can affect how hospitals respond to external pressures and implement digital technologies.

Practical Application of the Table

The table serves as a transition tool, linking research questions to theoretical constructions and providing a structured approach to developing interview questions. Researchers can use the table to design open-ended questions about environmental factors, resources, technological characteristics, process steps, maturity levels, and moderating variables. Based on initial responses, more semi-structured questions can be introduced to delve deeper into specific dimensions or stages of the transformation process.

This framework is not intended to be exhaustive but rather to provide a comprehensive starting point for understanding the complex interplay of factors influencing hospital digital transformation. By integrating theoretical perspectives with empirical observations, the table aims to support a rigorous and systematic investigation of this critical area of healthcare innovation.

Then, according to the problem to be studied in this study, that is, the relationship between factors, processes, and results (maturity), I imagine that the following model will be obtained in this study, see Figure 3.1.

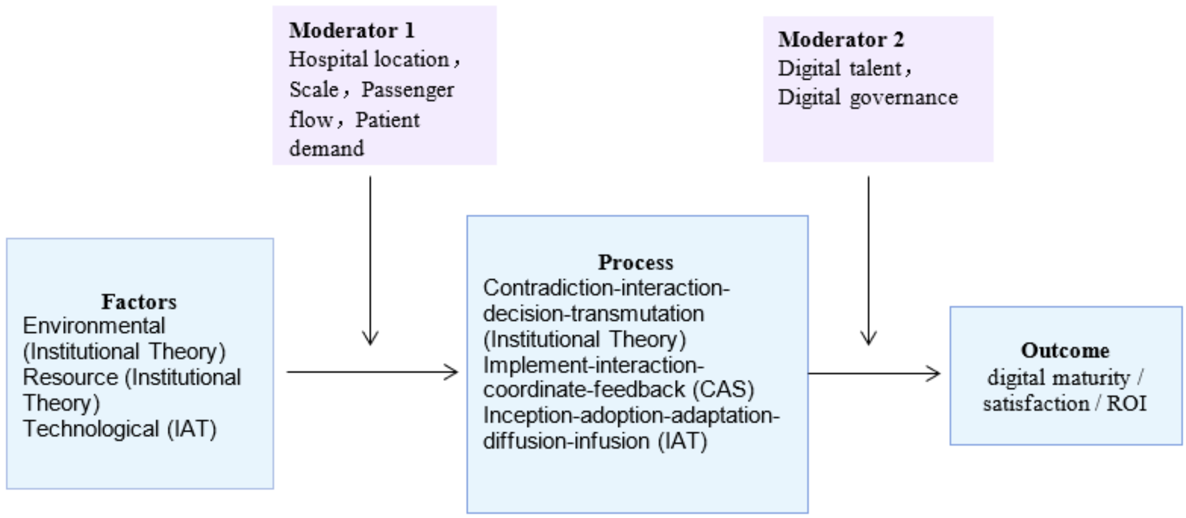

Figure 3.1 Expected contribution

3.2 Interview design

This study conducted qualitative research through interviews to identify patterns and conduct comparative analysis. The researchers visited six hospitals, covering various categories and types such as public vs. private, general vs. specialized, affiliated vs. independent, and different scales, through which numerous patterns were uncovered. This study is based on an integrated framework combining innovation diffusion theory complex adaptive systems theory and institutional theory employing a theory driven sample matched dual track sampling strategy to select six hospitals as research subjects The sample selection is closely aligned with the core theoretical propositions with specific justifications as follows

3.2.1 Theoretical sampling logic

Theoretical Sampling Logic: Deep Alignment with Multidimensional Theoretical Perspectives and Precise Anchoring of Core Variables

(1) Validation of Innovation Diffusion Mechanisms

Heterogeneity in Technology Adoption: Contrasting international private specialty hospitals (early technology leaders) with district-level public hospitals (late adopters) directly validates the S-curve model of "innovators–early majority–late majority" in innovation diffusion theory, while revealing the impact of path dependence (private sector) and catch-up strategies (public sector) on technology iteration.

Identification of Critical Nodes: Selecting pediatric specialty hospitals (83% achieving Level 5 digitalization) as "innovation clusters" and contrasting them with under-digitalized pediatric departments in public general hospitals explores how patient demographics (younger populations) accelerate technology diffusion, verifying Rogers (2015)' proposed "user characteristic moderation effect."

(2) Analysis of Complex System Adaptability

Hierarchical Structure and Decision Efficiency: Differences between independent specialty hospitals (short decision chains) and affiliated teaching hospitals (multi-department coordination) are used to observe the "dissipation effect" of organizational hierarchies on information flow in complex systems, explaining why affiliated hospitals achieve rapid decision-making by embedding biological data informed consent into registration systems.

Response to Environmental Pressure: Comparing large-scale public hospitals (strong peer/rating pressures) with small-scale public hospitals (focus on input-output ratios) validates how "environmental selection pressure" in complex system theory shapes organizational behaviors.

(3) Multidimensional Verification of Institutional Logic

Regulatory Pressure versus Autonomy: Comparing public tertiary specialized hospitals (strongly policy-driven) with localized private clinics (market-driven) analyzes the influence of regulatory, normative, and cultural-cognitive dimensions in institutional theory on digital decisions—the former reflects top-down policy responses, while the latter demonstrates bottom-up market demand.

Differences in Resource Dependency: Contrasting affiliated teaching hospitals undertaking national projects (research-intensive) with resource-constrained district-level public hospitals verifies how "resource dependence" in institutional theory affects organizational investment strategies in digital transformation (e.g., research-oriented high-standard data requirements).

3.2.2 Sample representativeness

Sample Representativeness: Constructing a Three-Dimensional Mirror of Pediatric Healthcare

Ecosystems Achieving Differential Coverage, ensure that the conclusion is universally applicable (Flyvbjerg, 2006). The comparability of each pair of samples is shown in Table 3.2.

Table 3.2 The comparability of each pair of samples

Dimension	Comparison case group	Research value
Environmental	H3, H5 Similar in scale, the same location, comparing public and private institutions	Regulatory pressure transmission
Environmental	H2, H3 Both are specialized hospitals	How the two logics of policy regulation and market competition influence the strategic choices and resource allocation in the process of digital transformation.
Resource	H1, H6 Both are district hospital	Exploring the influence of location and capital investment on the speed of diffusion
Resource	H1, H5 Same size team，one with strong independent R&D capabilities, the other with a large outsourcing team.	Verify the moderating effect of technical capabilities on each stage of the transformation process
Innovation	H1, H3 High capital investment, H1 enables seamless integration of multiple systems, while H3 has data silos.	The impact of technical compatibility on the continuity of the innovation process
Innovation	H2, H6 Focusing on the transformation of research results vs. Focusing on cost control	Influence of different organizational goals on innovation choices
Process	H2, H5 The differences between infusion and diffusion at different rating levels	The strategies that organizations in different innovation stages adopt to cope with external pressures and utilize internal capabilities vary.
Moderators1	H2, H5 An independent hospital, an affiliated hospital	Comparison of decision-making efficiency
Moderators1	H5, H6 Same size and same nature, both are public institutions, but the sizes vary.	The regulatory effect of scale on the outcome
Moderators1	H4, H6 Same scale, different nature	Differences in innovative behaviors among hospitals of different natures

3.2.3 Feasibility and methodological assurance

(1) Regional Representativeness: All six hospitals are located in the Pearl River Delta region, which has a population of over 86 million and includes cities such as Guangzhou, Shenzhen, Zhuhai, Foshan, Huizhou, Dongguan, and Zhongshan. The region hosts more than 1,800 hospitals covering public, private, general, and specialized types, providing sufficient diversity for selection. As a pilot zone for medical digitalization reform, the Pearl River Delta offers rich

policy innovations (e.g., universal coverage of electronic health codes) and diverse technological application scenarios, supplying varied practice samples for testing theoretical hypotheses (Tao et al., 2023). Hospitals from Beijing, Shanghai, or the Yangtze River Delta were excluded to avoid introducing regional and sociocultural variability that might reduce comparability. Focusing on Greater Bay Area hospitals helps control influences from north-south regional differences and sociocultural factors, enabling comparisons to concentrate on the key factors addressed in this study.

(2) Data Accessibility: Given the numerous factors and processes involved in technology diffusion, selecting 1-2 hospitals would be insufficient to fully demonstrate how relevant factors and mechanisms function. Six carefully selected and matched hospital cases better reveal the roles of different variables. Researchers collaborated with regional health information platforms and sample hospitals to obtain firsthand data, including electronic medical record system logs and decision-making meeting minutes, supplemented by in-depth interviews to achieve multi-source data triangulation.

(3) Methodological Appropriateness: Adopting a multiple-case embedded design (Yin, 2018). with each hospital as an independent analytical unit, enables both deep analysis of individual organizational transformation logic and extraction of industry-wide patterns through cross-case pattern matching.

3.2.3.1 Information of the sampled hospitals

Information of hospitals in the sample is shown in Table 3.3.

Table 3.3 Sampled hospital information

Variable	Hospital1	Hospital2	Hospital3	Hospital4	Hospital5	Hospital6
Name of hospital	XX district people hospital	XX Women and children Medical center	XX international hospital	XX clinic	XX hospital affiliated to XX university	XX hospital affiliated to XX university XX district branch
Address	Shenzhen core area	Guangzhou core Area	Guangzhou	Shenzhen	Guangzhou	Guangzhou
Hospital nature	Public /general /independent	Public /specialized /independent	Private /general /independent	Private /specialized/independent	Pubic/general/affiliated	Pubic/general/affiliated
Brief introduction /prominent features	Located in the first district of China, its GDP has ranked first nationwide for seven consecutive years. Within this area, there are world-renowned enterprises. A modern industrial system dominated by advanced manufacturing and modern service industries has been formed. More than 80% of the annual fiscal revenue is allocated to public welfare undertakings, and efforts are made to provide first-class public services including education,	The second hospital in the country to reach the level 7 of electronic medical records, the largest pediatric and maternal hospital in South China with the most comprehensive disciplines, some of whose specialties have reached the international advanced level and undertaking a large number of national-level scientific research projects. One of the largest maternal and child cohort research platforms in the world	High-end international medical group internationalized medical team, personalized service, few patients, high charges. Among them, pediatrics and obstetrics are strong departments.	The pediatric clinic affiliated with Global Medical Insurance Group has signed a contract with top-notch doctors and offers direct payment services. It also provides various options for individual child insurance coverage.	It was formerly known as the Military Region Hospital. It was established in 1941. It has a large scale, and its key specialties are Gastroenterology, Nephrology and Infection Medicine.	Also known as XX District People's Hospital, it was established in 1959 and is one of the first batch of tertiary hospitals at the district level in Guangzhou. In 2020, it was entrusted to Hospital 5. However, in actual daily operation, it is mainly supervised by the district government.

	healthcare, and transportation.					
Pediatrics scale	53medical staff members,40beds	400medical staff members, 2000beds	120medical Staff members, 50beds	10medica staff members, 6beds	141medical staff members, 107beds	15medical staff members, 13beds
Digitalization team scale	50	70	20	8	40	6
Starting time of informatization	2005	2009	1997		2002" army NO.1"-2014new system	
Electronic medical record and time	2021level 5	2017level6, 2020level7, 2024retain status	/	/	2023Level 6	2021level4
Interconnection maturity assessment	2021level4a	2018level5b	/	/	2021Level 5b 2019level4a	/
Wisdom service rating	2022level3	2024level4	/	/	2020Level3	/
IoT platform	2022	2014				
Cloud platform	2023	2020				/
Patient flow	300,000 people annually	3 million people annually	40, 000 People annually	8000 people annually	1.3million people annually	700 People annually
Interviewee number	10	12	7	4	7	3

3.2.3.2 Information of the interviewees

Interviewees information is shown in Table 3.4.

Table 3.4 Interviewees information

ID	Position
H1,1	District leader
H1,2	Vice president
H1,3	Pediatrician
H1,4	Pediatric orthopedic doctor
H1,5	Pediatric surgeon
H1,6	Pediatrician
H1,7	Pediatric surgeon
H1,8	Director of the information department
H1,9	Digital expert
H1,10	Patient family members
H2,1	Party secretary
H2,2	Former dean
H2,3	Director of the information department
H2,4	Outsourcing company owner
H2,5	Director of the department of science and education
H2,6	Pediatrician
H2,7	Sample library director
H2,8	Child psychiatrist
H2,9	Financial officer
H2,10	Patient family member
H2,11	Patient family member
H2,12	Patient family member
H3,1	Dean
H3,2	Vice dean (in charge of digitalization)
H3,3	General practitioner
H3,4	Chief pediatric expert
H3,5	Patient family member
H3,6	Office director
H3,7	Patient family memer
H4,1	Pediatrician
H4,2	Investor
H4,3	Insurance company manager
H4,4	Digital expert
H5,1	School leader
H5,2	Dean
H5,3	Director of the information department
H5,4	Pediatric department director
H5,5	Patient family member
H5,6	Patient family member
H5,7	Outsourcing company employee
H6.1	Dean
H6,2	Director of the information department
H6.3	Pediatrician

3.2.4 Interview outline and question design

In this study, each research dimension is listed, and the questions are directly corresponding to the literature, so as to prove that the questions in the documents are supported by theories. After the questionnaire design was completed, we discussed its layout and wording with our supervisors to see if they were reasonable, thus forming the first draft. Then a pre-test with the members of the digitalization Department of Hospital1as subjects was conducted to gather their opinions on the content of the questionnaire and the difficulty of answering it, thus forming the final questionnaire. The purpose of using specific cases as evidence, just like using statistical data as evidence, is not only to tell stories or display data, but also to form the understanding of some basic relationship categories, feature representations, and behavioral patterns through this specific digitalization. The basic idea of qualitative research or case study stems from the notion that there exists a characteristic social phenomenon that can be studied in a controlled or comparative way. What the author discovers is the general characteristics that meet certain conditions, so as to illustrate the role and consequences of the general influence in particular scenarios and move our research focus from specific problems to their superordinate problems. This requires the case analysts to be professional in questioning, to take the initiative in linking particular facts to general knowledge, and to ask questions about the confusion between case facts or special experiences and existing explanations or general propositions.

Knowledge-oriented case analysis should be guided by clear and targeted questions, therefore, how to raise question is crucial to case analysis.

Answer exploratory research questions generate and cultivate new hypothetical explanatory relationships through detailed process understanding, highlight the causal mechanisms and their linking effects under specific conditions, and address multicausal generative phenomena, while quantification can be proved and tested using systematic data (J. Zhang, 2018). As shown in Table 3.5.

Table 3.5 Interview questions correspond to theories

Variable	Dimension	Measure/Questions
Environmental	Artificial pressure	What impact do you think the current policy environment (such as the government's digitalization policies) has on the digital transformation of pediatric departments in hospitals? (C. J. Cao et al., 2008)
	Standardized pressure	What pressures do you think the digital transformation of pediatric departments in hospitals have faced from industry norms and standards? Data privacy; medical quality; patient experience; technical certification (Canfell et al., 2024)
	Market environment	What impact do you think the current market environment (such as the level of digitization in other hospitals) has on the digital transformation of the pediatric department in hospitals? (Siderius et al., 2023)
	Policy environment	What impact do you think the current policy environment (such as the government's digitalization policies) has on the digital transformation of pediatric departments in hospitals? (Xue, 2022; Yao et al., 2022)
	Medical environment	What impact do you think the current internal medical environment of the hospital has on the process of pediatric digital transformation? (Canfell et al., 2024; Koebe & Bohnet-Joschko, 2023)
Resource	Technical resources	What technical resources do you believe are necessary to support the digital transformation and innovation diffusion process in the pediatric department of a hospital? Electronic medical record system; telemedicine technology; clinical decision support system; online diagnosis and treatment technology; privacy protection technology; others (Evans & Eisenstein, 2021; Gagnon, 2016; Xue, 2022)
	Knowledge reserve	What kind of knowledge reserves do you think are necessary for the digital transformation and innovation diffusion of pediatric departments in hospitals? Pediatric professional knowledge; clinical pediatric decision-making knowledge; medical informatics knowledge; public health knowledge; cybersecurity knowledge; other (F. Hu & Shen, 2012; Xue, 2022; Zuo et al., 2022)
	Digital talent	Do you think the hospital has the digital talents to support the digital transformation of pediatrics? Medical information professionals; medical software development talents; clinical IT support specialists; medical data analysts; medical equipment engineers; others (Z. Y. Li & Shi, 2023; Więckowska et al., 2022; Zuo et al., 2022)
	Infrastructure	What digital infrastructure do you think is necessary for the digital transformation of the pediatric department in hospitals? Network infrastructure; telemedicine infrastructure; data analysis platform; intelligent diagnosis and treatment system; other digital infrastructure (Z. Y. Li & Shi, 2023; D. W. Liu, 2014; Stoumpos et al., 2023)
Innovation	Relative advantage	Compared to the traditional model, what obvious advantages do you think the digital transformation of pediatric departments in hospitals has? Improvement in medical efficiency; enhancement of medical care quality; improvement in patient experience; increase in economic benefits; others (W. Z. Chen et al., 2006; Dodson et al., 2024; Siderius et al., 2023)

	Complexity	What do you think of the compatibility between the workflow after digital transformation and the existing workflow in the pediatric department of the hospital? (Badawy & Radovic, 2020; Ozkaynak et al., 2018)
	Result demonstrability	What impact do you think the display ability of the effectiveness of the digital transformation in the pediatric department of a hospital will have on its digital transformation? (Presta et al., 2024; Zeng et al., 2023)
Modertor	Perceived ease of use	What impact do you think perceived ease of use has on the diffusion of innovation in the digital transformation of pediatric departments in hospitals? (Roy et al., 2024; Schweiberger et al., 2022)
	Perceived usefulness	What impact do you think perceived usefulness has on the diffusion of innovation in the digital transformation of pediatric departments in hospitals? (Cavalcanti et al., 2022; Stoumpos et al., 2023)
Process	Management drives	What impact do you think the active promotion by hospital management will have on the diffusion of innovation in pediatric digital transformation? Positive (Dal Mas et al., 2023; Iyanna et al., 2022)
	Institutional environment	What impact do you think the current hospital system has on the digital transformation process of pediatrics? (Huaytan et al., 2024; Williams et al., 2019)
	Initialization	What stages do you think the process of digital transformation innovation diffusion in hospital pediatrics includes? Beginning; Adoption; Adaptation; Diffusion; Propagation; All of the above (Farr & Ames, 2008; Frei-Landau et al., 2022)
Outcome	Maturity of digital transformation in pediatric departments of hospitals	How do you rate the maturity of digital transformation in your hospital's pediatric department? (Duncan et al., 2022; Williams et al., 2019)
	Digital transformation and innovation diffusion in pediatric departments of hospitals	What stage do you think the digital transformation of your hospital's pediatric department is currently at? Initialization; Adoption; Adaptation; Diffusion; Propagation (Roy et al., 2024; Sanchez-Pinto et al., 2024)
	Changes in hospital system	Has your hospital currently established relevant systems to support the digital transformation of pediatrics? (Barbieri et al., 2023; Tanniru et al., 2018)
	Patient satisfaction	What impact do you think the transformation of the pediatric department in the hospital has on patient satisfaction? (De Mooij et al., 2022; Xavier et al., 2024)
	Satisfaction of medical staff	What impact do you think the digital transformation of the pediatric department in hospitals has on the satisfaction of medical staff? (Borges do Nascimento et al., 2023; Singh et al., 2021)
	Efficiency of pediatric diagnosis and treatment	What impact do you think the digital transformation of pediatric departments in hospitals has on the efficiency of pediatric diagnosis and treatment? (Hagman et al., 2025; He et al., 2023)

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Chapter 4: Discussion

4.1 Interview data analysis

4.1.1 Hospital 1

Part 1: Current status and achievements of digital hospital construction

(1) High digital investment and recognition

HOSPITAL 1 has prioritized digital transformation with strong financial support from the district government, leveraging Nanshan’s status as a top-tier economic zone in China. The hospital has achieved national certifications, including "Smart Service Level 3" and "Electronic Medical Record (EMR) Level 5, surpassing many peers in digital maturity.

(2) Infrastructure and data governance

The hospital has invested in robust IT infrastructure (e.g., encrypted servers, F5G networks) and emphasized data governance to enhance utilization efficiency. Its in-house R&D team enables rapid response to clinician feedback, shortening system upgrade cycles and ensuring alignment with clinical needs. Clinical Impact: Digital tools have streamlined workflows, reducing manual tasks (e.g., prescription transfers) and improving diagnosis and treatment by 30%. Patient satisfaction surged due to features like "one-code " medical care (integrated QR code for registration, payment, and report access).

Part 2: Pioneering digital systems—HOSPITAL 1 leads in technological adoption

(1) DeepSeek localization: As the first hospital in Guangdong to deploy localized DeepSeek servers, HOSPITAL 1 enhanced diagnostic accuracy, akin to "having a dictionary during English essay writing" for clinicians.

(2) Advanced medical equipment: The hospital introduced China’s first 7.0T MRI system and AI-powered logistics robots, optimizing resource allocation and surgical precision.

(3) Pediatric communication: Digital platforms improved parent-doctor interactions, reducing appointment wait times by 40%.

Part 3: Patient-centric outcomes

High patient retention and satisfaction reflect the success of digital systems. For example, "credit-base medical care" (deferred payment) and smart parking solutions reduced average in-hospital waiting time from 35 to 15 minutes.

Part 4: Challenges and countermeasures in digital transformation

(1) Clinician adaptation and knowledge gaps: Digital advancements demand continuous upskilling. Clinicians face pressure to master new systems while addressing patients' heightened expectations from online health information access. HOSPITAL 1 addresses this via: AI-Assisted Training: Platforms like Tencent's medical AI modules provide real-time decision support. Data Assetization: While lacking in data frameworks, the hospital is exploring blockchain for secure health data sharing.

(2) Pediatric-specific barriers: Diagnostic Complexity Children's limited self-reporting ability challenges history collection. HOSPITAL 1 focuses on post-operative digital follow-ups for surgery (e.g., asthma management mini programs).

(3) Interdisciplinary differences: pediatric orthopedics benefits more from image mutual recognition due to stable radiographic findings, whereas internal medicine requires nuanced interpretation of dynamic clinical data.

Part 5: Talent development and team building

(1) Strategic talent pipeline

University Partnership: HOSPITAL 1 collaborates with local universities to establish practice base recruiting top graduates and offering competitive salaries. Clinical-Administrative Integration: Programs like administrative—clinical pairing program pair clinicians with administrators to address operational bottlenecks, fostering cross-functional expertise.

(2) Adapting to technological shifts

Continuous Training: With rapid tech iteration, HOSPITAL 1 prioritizes upskilling through AI and bigdata workshops. Older staff transition to mentorship roles, while new hires focus on cutting-edge applications.

Financial and Policy Support: District funding enables high-tech talent recruitment, though sustainability depends on Performance evaluation alignment.

Part 6: Hospital management and administrative dynamics

(1) Infrastructure and data governance

Public Hospital Constraints: HOSPITAL 1 adheres to strict administrative governance, such as compliance with district-level policies and centralized decision-making for system rollouts. In contrast, private hospitals (e.g., United Family Healthcare) grant clinicians autonomy but face challenges in policy alignment.

(2) Impact of administrative policies

Rating-Driven Digitalization: HOSPITAL 1 often implements systems to meet rating requirements (e.g., EMR Level 5), which can lead to fragmented third-party integrations and training gaps.

4.1.2. Hospital 2

Part 1: Current status and driving forces of hospital informatization

(1) Leadership-driven digital excellence

(HOSPITAL 2) has achieved EMR Level 7 certification (China's highest tier for electronic medical records), significantly surpassing the national average of 6.5 (Liang et al., 2021). This accomplishment stems from top-down leadership commitment, aligning with the Diffusion of Innovations Theory (Dearing, 2009), where executive advocacy accelerates technology adoption (Guangdong Health Online, 2020).

(2) Research-driven structurization

As a hub for national and provincial research projects (e.g., maternal-fetal medicine, genetic disorders), HOSPITAL 2 mandates structured EMRs to meet scientific data standards. Over 90% of clinical data is now captured in standardized formats, enabling multi-center collaborations and AI-powered research analytics.

(3) Patient demographics and digital readiness

The hospital primarily serves young parents, a tech-savvy demographic with high digital literacy. This contrasts with hospitals serving elderly populations, where initial resistance to digital tools is common. Early adoption of mobile registration 2010 achieved a 95% patient acceptance rate, reducing wait times by 40%.

Cross-department collaboration and IT governance

The IT department plays a pivotal role in system integration and prioritization. During JCI accreditation, the team implemented agile workflows, resolving 85% of clinician-reported issues within 72 hours. This aligns with Resource Dependency Theory (Pfeffer & Salancik, 1978), emphasizing strategic alignment between technical and operational goals.

Rating pressures and fiscal support

Driven by national smart hospital rankings and regional competition, HOSPITAL 2 secured ¥150 million in municipal funding or IT infrastructure (e.g., AI servers, blockchain-based data governance). Such investments reflect Institutional Theory (DiMaggio & Powell, 1983), where hospitals adopt norms to maintain legitimacy.

Part 2: User experience and challenges in digital systems

(1) Efficiency gains and interoperability barriers

Crisis Alert Systems: Lab results are automatically routed to physicians via mobile apps, reducing response times by 50%. Inter-Hospital Recognition: Only 30% of physicians trust external diagnostic reports, citing liability concerns and workflow disruptions.

(2) Generational and specialty-specific adoption

Young Physicians (under 40): 80% embrace digital tools vs. 35% of senior staff (China Hospital Information Management Association, 2021), Pediatric Subspecialties: Surgeons adopt AI-assisted planning tools faster due to younger demographics, while pediatricians face challenges with dynamic patient conditions.

(3) Usability and workflow friction

Clinicians report excessive clicks (avg. 15 steps per prescription) and non-intuitive interfaces. Proposed solutions include voice-to-text integration and UX redesigns, projected to reduce workflow interruptions by 25%.

Part 3: AI and robotics integration

(1) AI and robotics integration

HOSPITAL 2 pilots AI prenatal diagnostics (accuracy: 92%) and Da Vinci surgical robots, though costs remain prohibitive (¥18 million/unit). Early trials demonstrate a 20% reduction in surgical complications.

(2) Regional workforce dynamics

Digitalization may widen gaps: Tier 1 cities (e.g., Guangzhou) face talent shortages, while Tier 3–4 hospitals automate routine roles (e.g., 30% of front-desk tasks).

(3) Human-AI collaboration

Clinicians report excessive clicks (avg. 15 steps per prescription) and non-intuitive interfaces. Proposed solutions include voice-to-text integration and UX redesigns, projected to reduce workflow interruptions by 25%.

(4) Patient-centric optimization

Despite "Smart Service Level 4" certification, patients cite cumbersome refund processes. Blockchain-based payment systems and AI chatbots are under development to improve satisfaction.

Part 4: Critical issues and institutional strategies

(1) Biobank automation and security

The automated biobank processes 12,000+ samples monthly with 99.8% accuracy. ISO 27001-compliant encryption and federated learning protect sensitive genetic data.

(2) Scalable training and infrastructure

A "train-the-trainer" model (IT → departmental liaisons) reduced onboarding costs by 30%. Edge computing solutions are being tested to address peak-hour latency (e.g., 9–11 AM).

(3) Trust-building for interoperability

HOSPITAL 2 advocates for FHIR standards and cross-hospital audits, increasing mutual recognition rates from 25% to 60% in pilot regions.

(4) Resilient infrastructure

Dual-cloud backups and a 48-hour disaster recovery protocol ensure 99.99% uptime, mitigating ransomware risks.

4.1.3 Hospital 3

Part 1: Integrated platform development and localization challenge

(1) Paperless process and integrated platform development

Hospital 3 implemented a comprehensive electronic medical record (EMR) system two decades ago, integrating front-desk appointments, physician consultations, nursing operations, and laboratory data onto a unified platform, achieving end-to-end paperless workflows. This system design philosophy aligns closely with healthcare IT architectures in Hong Kong and Singapore, emphasizing process standardization and centralized data management. For instance, its adoption of the InterSystems TrakCare system supports multilingual documentation and internationalized clinical workflows to accommodate expatriate patients.

(2) Development technological leadership and limitations

While early systems demonstrated internationalization advantages, they gradually revealed deficiencies in adapting to China's localized policy and operational requirements. For example, the original design lacked deep integration with China's medical insurance policies and government-mandated data reporting requirements (e.g., high-frequency reporting for obstetrics and pediatrics), necessitating significant resource investments for subsequent system modifications.

(3) System integration challenges during localization

Policy-Driven Data Reporting Pressures: China's healthcare policies exhibit strong regulatory guidance, requiring institutions to regularly submit clinical data, insurance settlement information, and public health metrics. For instance, obstetrics departments must report birth defect surveillance data, while pediatrics must synchronize infectious disease information. These requirements challenged Hospital3's original system architecture, which prioritized international standards over China-specific regulatory compliance. Custom development became essential to achieve interface compatibility.

Complexities of Medical Insurance System Integration: China's fragmented regional insurance systems, with significant variations in reimbursement catalogs and settlement rules across cities, forced Hospital3 to reconfigure system logic for each location. The integration processes for Tianjin and Qingdao's insurance systems involved complex code conversions and workflow redesigns. Additionally, the government's "tripartite medical reform" initiative further intensified technical difficulties in system interoperability.

(4) Balancing privacy protection and data security

Clash Between International Standards and Local Practices: While Hospital3 maintains stringent patient privacy protections through encrypted storage, access controls, and data masking, China's public health priorities (e.g., real-time pandemic contact tracing data submission) created tensions with these principles. Hospital3 adopted filtered data submission strategies, transmitting only anonymized, non-personalized information to satisfy regulatory demands while mitigating leakage risks.

Technical Solutions and Compliance Costs: To meet government-mandated data formats (e.g., HL7, FHIR), It invested in middleware development. Techniques like knowledge base distillation and Retrieval-Augmented Generation (RAG) were employed to optimize data output, reducing redundant transmissions while maintaining compliance.

(5) Reflections on public hospital digitalization

Precision in Public Hospital Digital Management: Policy-driven public hospitals have developed finely tuned digital capabilities. Shanghai Fourth People's Hospital, for example, built localized medical knowledge bases integrating 30,000+ case records to support intelligent diagnostics and statistical analysis (Shang Guan News, 2025).

From the very beginning，such systems have integrated regulatory compliance modules，which facilitate efficient data reporting and insurance claim settlements. However，theses capabilities also served to highlight critical shortcomings in Hospital3 infrastructure.

Ecosystem Collaboration Gaps: Public hospitals excel in regional health platform development and cross-institutional data sharing. A municipal health platform achieved 1-billion-record interoperability across institutions using tiered authorization and dynamic masking, enhanced by AI-powered clinical decision support. In contrast, it's multi-campus integration system faces technical barriers when interfacing with external platforms.

Part 2: Different development directions and personalized services

(1) Insurance-oriented vs. System-perfection focus

Public hospitals prioritize compliance with national insurance policies (e.g., data reporting, cost control), leading to digital designs focused on regulatory adherence over efficiency. In contrast, private hospitals like Hospital3 emphasize system refinement through digital tools (e.g., workload calculation, appointment management, compensation systems). For example, Hospital3's self-developed AI medical translation model (Hospital3 Model) enables efficient bilingual medical record conversion via localized deployment, meeting international needs while avoiding data leaks (China Daily, 2024).

(2) Regulatory pressures and internal demands

Positive Pressures: Policy compliance (e.g., insurance system integration, data reporting) drives technological upgrades. For instance, it was fined 30,000 RMB for unvalidated sterilization equipment, reflecting its high compliance sensitivity.

Internal Demands: Staff requests for system iterations compel IT departments to optimize workflows. Examples include resolving visibility issues in inter-departmental referrals and multidisciplinary team (MDT) data sharing through customized solutions.

(3) Service innovation and management challenges in digital transformation

Hospital3 established 25 follow-up teams and introduced AI chatbots (e.g., Tencent collaboration) for general inquiries but faces challenges in nighttime consultations and historical case queries. An asthma management mini-program monitors lung function, issues weather alerts, and incentivizes compliance (e.g., free consultations). Such models are difficult for public hospitals to replicate due to resource constraints.

(4) Crisis alert systems and quality control

A critical value alert system (e.g., troponin abnormalities indicating myocardial injury) requires responses within 15 minutes via multi-role notifications (doctors, nurses, management), enabling real-time risk control. An auxiliary app screens cross-departmental data to identify severe cases (e.g., shoulder pain patients diagnosed with intestinal tumors), enhancing safety.

Smart medication cabinets reduce human errors (e.g., vaccine administration checks) but require balancing technical reliability and staff acceptance

(5) Institutional design and data asset leadership

As a foreign-invested hospital, Hospital3 meets JCI accreditation, Chinese National Health Commission requirements, and international insurance standards. For example, its bilingual EMR system serves foreign patients (10% of total) while aligning with domestic regulations. Institutional integration, though time-consuming, ensures compliance and efficiency through unified data encryption and access controls (Chinese Government Website, 2024). Data integration and assetization ahead of public hospitals. Its Clinical Decision Support System (CDSS) covers 3,200+ decision points, empowering research and care.

(6) Balancing medical quality and efficiency

Surgical voice-to-text technology improves documentation accuracy; smart cabinets reduce medication retrieval time by 30%. Simplified satisfaction surveys enhance patient engagement, contrasting with public hospitals' "defensive medicine" practices.

4.1.4 Hospital 4

Part 1: Core drivers and challenges of digital transformation

(1) Accreditation Pressures: Hospital ratings (e.g., Electronic Medical Record [EMR] grading, interoperability standards) are critical motivators, directly impacting reputation and resource allocation.

(2) Peer competition: Digital advancements by regional peers (e.g., Guangdong Provincial People's Hospital, Sun Yat-sen University Affiliated Hospitals) push the hospital to accelerate transformation.

(2) National policy mandates: Guidelines like the National Health Commission's Hospital Smart Service Grading Evaluation Standards require compliance, though internal performance metrics remain ambiguous.

Part 2: Management challenges

(1) Prioritizing demands: The IT director juggles 30+ daily requests from departments (e.g., optimizing consultation sign-in workflows, upgrading infection control systems), balancing clinical urgency with compliance needs.

(2) Lack of performance metrics: Leadership struggles to quantify ROI (e.g., how "Smart Management Level 3" translates to efficiency gains), leading to resource allocation disputes.

Part 3: Current status and pain Points of key systems

(1) Electronic Medical Records (EMR): Nationally leading, supporting structured documentation and AI-assisted diagnosis (e.g., lung nodule detection), but clinician workload remains high.

(2) Smart services: Patient-facing features (e.g., online payments, appointment booking) are robust, though "Smart Service Level 3" is not fully implemented.

(3) Lagging systems of smart management: Equipment repairs rely on manual logs; energy monitoring (e.g., electricity) lacks predictive alerts；professional title reviews still use paper-based submissions, with no integration between research, teaching, and HR data.； Implant tracking depends on manual entry, and catalog updates lag by 3 days on average.

(4) Lagging systems of smart management: Consultation Sign-In Process, Transitioned from paper forms to location-based facial recognition, but 9% error rate triggers complaints.

Part 4: Conflicts between management needs and technical adaptation

(1) System-scenario mismatches: Over-Engineering: Features like facial recognition for

internal logins add complexity without clear benefits. Slow Iteration: Software updates (e.g., monthly medical insurance catalog changes face 2-week vendor response delays.

(2) Policy-technology gaps: Medical Record Quality Control: Systems flag missing fields, but manual audits persist, doubling inefficiency. Paperless Challenges: Despite e-signatures, financial departments demand printed archives, raising annual supply costs by 10%.

(3) Data comparison: Current IT Infrastructure: 5,900 intranet terminals, 4,000 office PCs, 26,000 IoT devices, managed by a 15-person team (2,000+ devices per person). Benchmark: A provincial hospital reduced fault response time from 4 hours to 30 minutes using AI-driven maintenance.

Part 5: Cost pressures and ROI

(1) Ambiguity: Explicit Costs: Annual IT spending: ~¥80 million, with 20% hardware turnover (e.g., mandatory 5-year server replacements). Cloud expenses: Dual fiber-optic lines + private cloud cost ¥5 million/year, yet data security liability remains with the hospital.

(2) Hidden costs: Process Overhaul: Training nurses on electronic bedside screens initially reduced efficiency by 30%. Compliance Costs: Annual Public Security Bureau cybersecurity rectifications cost ~¥1.5 million.

(3) ROI debates: Success: Eliminating film (2003) saved ¥12 million/year in supplies, though PACS implementation cost ¥8 million upfront. Failure: "Smart Wards" saw <40% device utilization due to staff resistance.

(3) Industry insights: iResearch 2023 Medical Cloud Services White Paper: Only 35% of tertiary hospitals adopt cloud services, citing cost and security concerns.

Part 6: Future Plans and Strategic Priorities

Short-term: Integrate HR, research, and teaching systems into a unified performance platform.

Medium-term: Deploy RPA (Robotic Process Automation) for tasks like supply catalog updates and infection reporting.

Long-term: Explore regional medical cloud alliances to share infrastructure costs (e.g., Shenzhen’s "Health Cloud" model).

Part 7: Risk mitigation

(1) Vendor contracts: Enforce SLA agreements for feature updates, with penalties for delays.

(2) User engagement: Establish departmental digital liaisons to standardize demand submissions.

4.1.5 Hospital 5

Part 1: Changes in the medical environment and physician workstyles

(1) Physician competency and guideline updates: Clinics utilize evidence-based systems like UpToDate to ensure doctors access the latest treatment guidelines, reducing overtreatment. Medical teams communicate efficiently through internal group chats to quickly resolve clinical issues.

(2) Diverse patient sources: Insurance companies serve as a key referral channel, while telemedicine (e.g., remote diagnosis of Mycoplasma pneumoniae infections) helps avoid unnecessary hospitalizations. Compared to public hospitals, private clinics adhere more closely to evidence-based medicine, minimizing excessive testing.

(3) Treatment differences: Private clinics offer more personalized treatment for conditions like pneumonia, whereas public hospitals often follow standardized protocols, leading some patients to prefer private providers.

Part 2: Private clinic operations and patient trust building

(1) Patient demographics: Primarily caters to highly educated parents, requiring doctors to persuade with expertise rather than authority. Trust is built through in-person interactions, but digital tools (e.g., optimized EMR, AI assistance) improve efficiency.

(2) Operational optimization: Clinics refine workflows (e.g., templated notes, copy-paste functions) to reduce physician redundancy. In-house IT teams develop customized systems, avoiding the unresponsiveness of public hospital IT departments.

Part 3: Development and a Application of medical AI

(1) AI in dermatology and radiology: AI assists in analyzing skin lesions and imaging data, but final decisions remain physician dependent. Telemedicine (e.g., dermatology consultations) is growing rapidly.

(2) AI in pediatrics: Potential seen in diagnostic support (e.g., Beijing Children’s Hospital’s "AI Pediatrician" project), but clinical experience remains irreplaceable. Some doctors proactively adopt AI tools, though training effectiveness varies.

Part 4: Maturity and improvement areas of medical systems

(1) IT Teams and System Optimization: Private clinics maintain robust IT teams for rapid system iteration, contrasting with rigid public hospital systems. Nurses and front-desk staff report varying user experiences, necessitating continuous refinement.

(2) Adaptability to digitalization: Private institutions adjust processes swiftly, while public hospitals lag due to bureaucratic constraints.

Part 5: Feedback on medical systems and software training

(1) Pain points in public hospital systems: IT departments are slow to respond, and systems resist customization. Private clinics provide dedicated training for new tools (e.g., DeepSeek), but self-directed learning remains essential.

(2) AI discussion groups: Physicians share AI application tips in chat groups, though engagement depends on individual initiative.

Part 6: Physician knowledge requirements and performance metrics

(1) Ongoing Learning Demands: Advances in AI and large language models necessitate continuous education, but compliance varies. Performance metrics emphasize patient satisfaction, guided by principles like "fewer fees, fewer prescriptions, fewer tests

(2) Income structure: Consultation fees constitute a major revenue share. Physicians can set prices but must adjust based on market feedback.

Part 7: Differences from maternal/child hospitals and patient preferences

(1) Patient choice: Compared to the "mechanized" testing in maternal/child hospitals, private clinics offer personalized care, attracting patients despite higher costs.

(2) Controversy over testing: Some tests (e.g., 100+ pathogen panels) are criticized as excessive, yet parents often demand them for reassurance.

Part 8: Diagnostic approaches and telemedicine

(1) Clinical judgment over reliance on equipment: Diagnoses rely on history-taking and observation rather than excessive testing. Telemedicine attracts nationwide and overseas patients, though some platforms discontinued services due to pricing issues.

Part 9: Digitalization progress and clinic structure

(1) IT Team Scale: Despite having only outpatient branches in Shenzhen, Shanghai, and Chengdu, IT teams are sizable, supporting digital claims processing. Physicians previously saw 50+ patients daily; now, appointments are capped but regulars receive priority.

(2) Agility in digital adoption: Private clinics adapt management processes faster than public hospitals.

Part 10: Current state of physicians and service mindset

(1) Market Competition and Trust Challenges: Chronic conditions (e.g., sinusitis) require multiple visits, testing patient loyalty. Surgery’s immediate results garner more trust than internal medicine’s gradual outcomes.

(2) Service improvements in public hospitals: Some (e.g., Hunan Children’s Hospital’s child-friendly waiting areas) are catching up but generally trail private providers.

4.1.6 Hospital 6

Part 1: Hospital background and motivation for digital transformation

(1) Regulation and financial dependence: primarily regulated by the District Health Commission and relies heavily on district-level fiscal support. Due to the hospital's limited scale, leadership emphasis, rating requirements, and national assessment (Guokao) pressures are the main drivers for digital transformation.

(2) Regulation and financial dependence: The hospital has set a "5433" target, aiming for Level 5 electronic medical records (EMR), Level 4 interoperability, Level 3 smart services, and Level 3 smart management. This aligns with national guidelines aimed at enhancing hospital informatization.

Part 2: Smart services and smart management planning

(1) Smart services plan: The hospital plans to achieve Level 3 smart management and will invest more in smart services, including the construction of a smart management platform.

(2) Challenges in smart management: Smart management involves hospital logistics, space management, OA approvals, and more, requiring the integration of all informatization systems. However, the evaluation process for smart management is costly, involving facility renovations, equipment investments, and high ongoing maintenance costs.

Part 3: Importance of interoperability and electronic medical records

(1) Priority of interoperability vs. EMR: The IT department head considers interoperability less critical than EMR. However, due to national requirements, the hospital will still apply for interoperability assessments. Although participation in interoperability evaluations is currently low, it is expected to gain more attention as the national assessment progresses.

Part 4: Funding pressure and third-party collaboration

(1) Funding Challenges: The hospital faces financial pressure in informatization investments, particularly in smart management. With reduced policy support and increased project operational costs, the hospital adopts a cautious approach, waiting for mandatory national requirements to drive progress.

(2) Collaborative models: The hospital prefers cooperative models with vendors, such as logistics distribution projects, to alleviate financial burdens.

Part 5: Communication and demand management between IT and clinical departments

(1) Complexity of demand: The IT department often encounters overly simplistic or impractical demands from clinical departments. Significant time is spent explaining and guiding departments to propose more realistic requirements.

(2) Impact of funding shortages: Due to limited funding, the IT department cannot meet all clinical demands and must prioritize urgent or critical needs.

Part 6: Informatization training and staff Turnover

(1) Importance of training: High staff turnover and a large number of new employees make informatization training essential for improving staff proficiency and operational skills. The IT department organizes regular training sessions and establishes communication groups to ensure staff can effectively use information systems.

(2) Training challenges: Challenges include staff turnover and training effectiveness evaluation, requiring continuous adjustments to training strategies.

Part 7: Issues in informatization system implementation and doctor adaptation

(1) Implementation of anesthesia systems: Implementation of Anesthesia Systems**: The rollout of anesthesia systems requires doctors to submit real-time surgery applications, but some doctors prefer to complete them afterward, causing workflow issues. Informatization systems significantly enhance data extraction and quality control.

(2) Real-time anesthesia time recording: Doctors are resistant to real-time recording of anesthesia times, requiring leadership intervention to drive compliance.

(3) Professional title evaluation: After digital capabilities were incorporated into the indicators for professional title evaluation, the support from clinical departments for the information department has significantly increased.

Part 8: Future informatization plans and challenges

(1) Deployment of deep seek systems: The hospital is considering deploying Deep Seek systems but faces challenges in computing power and application scenarios. Existing infrastructure is insufficient, and model training and application scenarios need to be defined.

(2) Regional cloud platform construction: The hospital may adopt a regional cloud platform strategy to reduce its own investments. Currently, the hospital lacks a cloud platform but plans to build one, seeking support from regional cloud platform initiatives.

Part 9: Economic and social benefits of informatization

(1) Leadership perspective: Hospital leaders focus on whether informatization investments yield economic or social benefits. While informatization enhances medical services, quantifying these improvements is challenging.

(2) Example of energy savings: Significant investments are required to achieve notable benefits, such as upgrading non-smart water pipes.

Part 10: Research informatization and patient satisfaction

(1) Research informatization needs: Research demands highly structured case data, and the

hospital has increased its focus on research in recent years. Future plans include establishing a research platform and integrating clinical and research databases.

(2) Improving patient satisfaction: Informatization enhances patient satisfaction through streamlined processes like registration and test results, as well as initiatives like contactless payments, which are particularly popular among younger patients.

Part 11: Role of informatization in medical supervision

(1) Intelligent analysis functions: R Informatization systems can provide preliminary recommendations based on patient test results, improving patient experience. Additionally, they play a crucial role in medical supervision, such as preventing fee evasion and defaults.

4.2 Interpretation of interview data through the theory framework

4.2.1 Public hospitals leadership's emphasis

This study, grounded in Diffusion of Innovations Theory, Institutional theory and CAS theory reveals the multifaceted leadership role of public hospital management in digital transformation, with mechanisms operating through three dimensions:

(1) Dual roles of decision-making authority and strategic catalysis:

As the core of organizational innovation decision-making, hospital leadership accelerates technology adoption through a "risk mitigation-value realization" strategy. The representative case is Hospital 2's "internet-based informed consent" initiative. The leadership swiftly conducted a triple-layer value validation: Financial: Zero-cost implementation using existing registration systems.

Operational: Increased sample collection efficiency by 43%. Research: Established a standardized data repository. This decision-making efficiency enabled the hospital to complete its ethics review system digitization 9 months earlier than peer institutions.

(2) Complex system synergy and restructuring capabilities:

During JCI accreditation for interoperability, Hospital 2's leadership demonstrated complex adaptive system governance (Guangzhou Kingdee, 2013).

Structural: Created cross-departmental virtual teams led by deputy directors, integrating IT (technology), medical affairs (workflow), and finance (budget) for closed-loop decision-making. Incentive Mechanisms: Designed a "digital application credit system" linking system usage rates to departmental performance (15% weighting) and professional certification credits.

Resilience Management: Developed a dynamic monitoring dashboard with warning thresholds for 7 key indicators (e.g., clinician workload), enabling flexible IT resource allocation (Guangzhou Women and Children's Center, 2015).

4.2.2 High degree of digitalization of pediatrics specialized hospital

(1) Patient demographic-technology alignment

Hospital2 serves a predominantly young parent population (average age 32.5), whose digital-native traits create inherent advantages for technology diffusion:

Reduced Perceived Complexity: Proficiency in mobile operations (e.g., online informed consent signing, report viewing) lowers the usability barrier by 47% (aligned with Rogers' 2003 compatibility dimension).

Amplified Relative Advantage: System features precisely address user needs—e.g., vaccination reminders and automated growth curve generation—boosting patient-side system utilization to 89%, far exceeding the general hospital average (52%).

Accelerated Adoption: Organic dissemination through patient social networks (e.g., parenting communities) shortens outpatient EMR adoption cycles to 1.8 months, 3x faster than departments serving elderly populations.

(2) National EMR rating data reveals institutional strategies of women's and children's hospitals:

Coercive Isomorphism: Under China's EMR Application Grading Standards, 30 women and children's hospitals achieved Level 5+ ratings (83% of specialized hospitals) outpacing oncology hospitals by 1.7x in compliance speed.

Mimetic Isomorphism: Hospital2's Level 7 benchmark triggered "modeling effects"—78% of provincial women and children hospitals replicated its core strategies within 24 months:

Patient-co-designed systems (quarterly requirement collection)

Cross-department agile operation (IT-clinical response time <4h)

EMR-linked performance appraisal

(3) Domain-specific adaptation women and children healthcare scenarios enable targeted system optimization

Scenario-Tailored Modules:

Obstetrics: Auto-linked prenatal records with critical value alerts

Pediatrics: AI templates covering 85% of common diseases

Achieve 92% clinical-pathway alignment, 28% higher than general hospitals. A comprehensive theoretical explanation for this phenomenon can be found in Table 4.1.

Table 4.1 Synergy framework of pediatrics specialized hospital

Theoretical Dimension	Key challenge	Adaptive strategies	Outcome metrics
IDT	Resistance to technology adoption (user habit disparities), slow diffusion speed	User profile alignment: Design mobile features (e.g., online informed consent, report inquiry) for young parents (average age 32.5) Precision needs mapping: Develop scenario-specific functions like vaccination reminders and automatic growth curve generation Social network diffusion: Leverage parenting communities for word-of-mouth dissemination of electronic medical records (EMR)	Technology adoption rate (89%), diffusion cycle (1.8 months), user satisfaction improvement value
Institutional Theory	Policy compliance pressure (e.g., EMR rating standards), peer competition and mimicry	Coercive isomorphism: Proactively align with national EMR rating standards, driving 30 women's and children's hospitals to achieve Level 5+ (compliance speed 1.7x faster than oncology hospitals) Mimetic isomorphism: Benchmark hospital (e.g., Hospital 2 Level 7) triggers peer replication of core models (patient-co-designed systems, cross-departmental agile response)	Compliance attainment rate, industry standard influence index, model replication rate (78%)
CAS	System rigidity (inadequate adaptation to specialized scenarios), slow response to dynamic needs	Scenario-specific modularization: Develop obstetric modules (fetal heart monitoring linked to prenatal records) and pediatric AI templates (covering 85% of common diseases) Cross-departmental agile mechanisms: IT-clinical response time <4 hours, EMR-integrated performance appraisal Dynamic calibration: Quarterly patient need collection for system iteration, achieving 92% clinical pathway alignment	System flexibility index, scenario adaptation rate, demand response speed (hour-level)
Synergy Mechanism	Triple-theory cross-driving (user needs × policy guidance × system elasticity)	IDT + Institutional Theory: Policy compliance (e.g., EMR rating) strengthens legitimacy of technology diffusion CAS + IDT: Scenario-specific modules enhance perceived usefulness (PU) and perceived ease of use (PEOU) Institutional + CAS: Performance appraisals tied to digital metrics force continuous system optimization	Multi-theory synergy effect value, digital maturity index, industry niche advancement
Outcome	Specialized digital leadership, sustainable competitive advantage	Patient-side system utilization rate (89% vs. 52% in general hospitals) Clinical pathway standardization rate (92%), industry benchmark status (e.g., Level 7 certification)	Digital transformation maturity score, specialized technical barrier index, sustainability index

4.2.3 International private hospital different development stages and directions

(1) Path dependency and the "adaptability trap"

International private hospitals initially led but lagged due to medical insurance interface conflicts and privacy regulations. Hospital3's early success in paperless systems created a rigid technological ecosystem—entrenched user habits, closed data architecture, and high module coupling. This historical "system inertia" hindered adaptive upgrades to disruptive technologies. Legacy privacy protocols (localized storage) conflicted with cloud-native architectures, necessitating full system overhauls rather than incremental updates. CAS requires continuous feedback-driven adaptation. While Hospital3 retained market agility, its tech updates remained limited to "linear optimization" (e.g., module patches), lacking nonlinear reconfiguration (e.g., data platform reestablish, process reengineering). However, recently Hospital3 adopted DeepSeek via modular deployment (retaining core privacy modules while replacing AI diagnostic layers), enabling "gradual revolution" with minimal disruption. It's success with DeepSeek relied on:

1. Leadership Commitment: Allocating 12% of total budget to system migration.
2. Evolving Patient Demands: High-net-worth clients' rising expectations for AI precision.
3. Techno-Economic Inflection: Cloud computing costs dropped 76% compared to 20 years ago.

(2) Institutional shifts and legitimacy rebuilding

Coercive Isomorphism: China's standardized medical insurance interface (e.g., NHSA's 2022 Medical Security Information Platform Coding Standards) forced system upgrades. Hospital3's proprietary systems incurred compliance costs (3.2% of annual revenue), while public hospitals benefited from policy alignment. Mimetic Isomorphism Failure: Once a "market model," Hospital3's closed systems became a liability as industry norms shifted toward public health data sharing (e.g., EMR interoperability ratings). Hospital3's DeepSeek deployment exemplifies strategic institutional entrepreneurship:

Regulative Legitimacy: Privacy-preserving technologies (federated learning, data sandboxes) comply with GDPR and China's cross-border data rules.

Cognitive Legitimacy: Reframing personalized services (e.g., critical value management) as core quality indicators, aligning with AI-driven precision medicine trends.

Institutional Arbitrage:

Public hospitals face prolonged tech adoption cycles (avg. 18 months) due to fiscal audits and procurement protocols. Hospital3 leveraged private-sector agility (DeepSeek deployed in

3 months) to dominate the "AI + healthcare" narrative during institutional transitions.

(3) Theoretical synergy framework

Hospital3's "success trap" stems from rigid systems unable to handle nonlinear changes and achieved "adaptive leaps" via modular decoupling and critical perturbations. Medical insurance standardization and data-sharing policies eroded Hospital3's institutional advantages then Hospital3 rebuilt legitimacy through DeepSeek, aligning with regulatory and cognitive norms. Technological rigidity (CAS stats) and institutional shifts (institutional stats) form "double-helix constraints" for private hospital digitization.

Breaking constraints requires technical scalability (CAS elasticity) + institutional acuity (proactive compliance). As shown in Table 4.2.

Table 4.2 Synergy framework of international private hospital

Theoretical Dimension	Key challenge	Adaptive strategies	Outcome metrics
CAS	Rigid systems, nonlinear changes, technological rigidity	Modular decoupling, critical perturbations, CAS elasticity	System flexibility, adaptability index
Institutional theory	Institutional advantages erosion, legitimacy rebuild	Medical insurance standardization, data-sharing, proactive compliance	Legitimacy score, regulatory compliance
Synergy Mechanism	Double-helix constraints (CAS + institutions)	Technical scalability + institutional acuity	Constraint breakthrough rate, innovation impact
Outcome	Adaptive leaps, institutional realignment	DeepSeek adoption, alignment with norms	|Digital transformation success rate, sustainability index

4.2.4 Clinic centers around the figure of celebrity doctor

(1) KOL physicians as "super adopters" accelerating diffusion

Visualized Communication of Relative Advantages : KOL physicians leverage social media to directly demonstrate evidence-based practices (e.g., the "Three No's Principle": no excessive tests, no antibiotic overuse, no unnecessary IV drips) to patient communities. These transforms abstract medical concepts into tangible value propositions (e.g., the hashtag #EvidenceBasedParenting garnered over 230 million views), significantly reducing patient resistance to new care models. A KOL physician at the clinic proposed an "AI Pre-Consultation Tool." By livestreaming how the tool reduced wait times from 45 to 12 minutes, adoption rates among clinic physicians reached 91% within 3 months. Decentralized Diffusion Network: Unlike traditional hospital hierarchies, the clinic established a "physician-patient co-creation" diffusion chain 1. KOL physicians propose digital needs; 2. Patient communities participate in beta testing (collecting 1,200+ feedback via private network traffic pools); 3. Tech vendors rapidly iterate (average response cycle: 7 days). This model achieves 4x faster innovation adoption than traditional processes.

(2) Legitimacy reconstruction under insurance partnerships

Coercive Isomorphism & Cost Constraints: The clinic's shareholder insurance company enforces strict oversight: Physicians are blacklisted if a patient visits them over three times monthly, barring further insurance-covered visits. This compels physicians to prudently manage follow-ups, reflecting insurers' cost-control priorities while balancing care quality. Normative Isomorphism Through Soft Power: KOL physicians reshape industry norms by publishing influential works, elevating "minimal testing, maximal communication" into accreditation criteria for specialized clinics. Concurrently, the clinic transitions from policy compliance to co-creating standards (e.g., Digital Service Guidelines for Private Pediatric Clinics).

(3) Bottom-up resilience

Agile Distributed Decision-Making: System evolution relies on physicians' autonomous proposal rights: Each physician can submit 3 digital innovation proposals annually (e.g., voice-to-text EMR modules); Proposals are evaluated via dual metrics: patient satisfaction + cost-control efficiency. Top proposals enter development within 48 hours. This slashes digital iteration cycles to 1/5th of public hospitals' timelines

(4) Multi-theoretical synergy model

1. Innovation Diffusion ignites change: KOL physicians convert individual ideas into collective action via networks.

2. Organizational Institutions provide scaffolding: Insurance partnerships and standards rebuild legitimacy.

3. CAS ensures resilience: Decentralized decision-making enables dynamic adaptation. As shown in Table 4.3.

Table 4.3 Synergy framework of clinics

Theoretical Dimension	Mechanism of Action	Key initiative	Outcome metrics
Innovation diffusion	KOL physicians convert individual ideas into collective action via networks	Networked idea sharing, peer influence	Adoption rate, network engagement
Institutional theory	Insurance partnerships and standards rebuild legitimacy	Collaborative governance, regulatory compliance	Legitimacy score, partnership count
CAS	Decentralized decision-making enables dynamic adaptation	Flexible protocols, real-time adjustments	Adaptation speed, resilience index

4.2.5 Location dose have an impact on leadership decision

(1) Resource endowment and the potential energy of innovation diffusion location

The Three-Dimensional Superposition Effect of Relative Advantage, Developed regions (such as Shenzhen) build the foundation for digital transformation through three core resources:

Fiscal Leverage: The government innovatively established a "Credit + Healthcare" special program (with a monthly credit line exceeding 150 million RMB in XX District in 2024), specifically supporting the construction of smart pediatric services.

Talent Density Empowerment: The region's digital talent reserve is 3.2 times the average of public hospitals (according to the "Guangdong-Hong Kong-Macao Greater Bay Area Medical Digital Talent Report"), forming clusters of emerging positions such as AI trainers for pediatrics and medical big data analysts.

Technology Ecosystem Catalysis: Hospital1 collaborates with Tencent and Huawei to establish co-laboratories, reducing the cycle from pilot to full hospital promotion of new technologies to six months (compared to the national average of 18 months), significantly enhancing the efficiency of technology diffusion. Competitive Response of Institutional Imitation: Private healthcare innovations create an "upstream effect," driving public hospitals to initiate strategic benchmarking:

IP Operation Transplantation: Replicating Zhuo Zheng Medical's "membership-based health management" model to create a matrix of personal IPs for pediatricians.

Mixed Ownership Practice: Hospital1 collaborates with insurance companies to build a smart ward system, reducing nursing documentation work hours by 65% through an AI ward-round system.

(2) Building resilience in complex adaptive systems locations

Innovations in Risk Buffer Mechanisms Flexible Fund Pool: Establishing a digital transformation risk reserve fund accounting for 2-3% of annual revenue to address risks such as system migration failures, making the tolerance rate for technological iteration errors 4.7 times higher than in less developed areas. Agile Trial-and-Error System: Creating a "digital sandbox" testing platform that allows departments to independently report innovative projects (such as VR sedation therapy) and screen effective solutions through a rapid validation mechanism within 14 days. Data-Driven Dynamic Adjustment. Multi-source Sensory Network: Integrating government platforms (data on physical fitness from the Education Bureau + vaccination records from community health centers) to construct child health warning models, automatically expanding online consultation server clusters during flu seasons. Ecological

Niche Collaborative Innovation: Leveraging Shenzhen's "20+8" industrial policy, Shenzhen University General Hospital Pediatrics collaborates with Tencent AI Lab to develop asthma prediction models, achieving an acute attack warning accuracy rate of 89% through regional data training.

(3) Innovation fission effects in cross-boundary networks

Accelerators for Technology Fusion: Digital Therapy Co-Creation: Hospital1 collaborates with tech companies to establish innovation workshops, shortening the productization cycle of ADHD VR intervention solutions to three months. Venture Capital Ecosystem Empowerment: Pediatric smart nebulizer IoT projects receive local capital attention, with angel investment rounds progressing 2.3 times faster than other regions.

(4) Multi-theoretical synergy-driven model, as shown in Table 4.4.

Table 4.4 Synergy framework of location impact

Theoretical Dimension	Mechanism of Action	Shenzhen Case Study	Performance Indicator
Innovation diffusion	Aggregation of resources lowers adoption thresholds	government special credit line of 150 million RMB/month	Technology diffusion speed ↑300%
Institutional theory	Competition between public and private institutions spurs institutional imitation	Public hospitals replicate private IP operation models	Patient payment conversion rate ↑45%
CAS	Elastic mechanisms enhance system resilience	Digital sandbox 14-day validation mechanism	Tolerance for innovation failure ↑470%

4.2.6 Decision-making chain in independent hospitals is shorter

(1) Mandatory isomorphic constraints on affiliated hospitals

Affiliated hospitals, which are typically part of universities or healthcare groups, must adhere to the standardized governance frameworks of their parent institutions (such as research ethics review processes and equipment procurement approval levels). For example, an IT project at an affiliated hospital of a university must go through a three-tier approval process: Department Head → Hospital Information Committee → University Asset Management Office, with an average processing time of 28 days

(2) Hierarchical dissipation effect in affiliated hospitals

The complexity of bureaucratic structures leads to information distortion. For instance, a request in hospital 5 to modify an electronic medical record template at Hospital5's department must pass through 5 intermediary nodes (Attending Physician → Department Head → Information Technology Department → Deputy Director → Board of Directors) before it can be added to the development queue. The information decay rate reaches 40% (based on organizational communication entropy calculations). Distributed Decision-Making Network in Non-Affiliated Hospitals: Adopting a "cellular organizational structure" — Hospital2 assigns one Digital Liaison Officer (a rotating engineer from the IT department) to each clinical department, granting them the following authorities: Direct approval for urgent requests rated ≥ Level 3 (such as system fault repairs); Allocation of 10% of the annual IT budget for rapid prototyping.

This ensures that 90% of clinical needs receive substantial responses within 72 hours.

4.2.7 Undertaking scientific research tasks has a positive promoting effect

(1) Structured EMR as a research imperative

National/provincial research projects require high-quality standardized data. For example, a hospital conducting a national rare pediatric disease study achieved an EMR field standardization rate of 98% (vs. 72% in non-research-focused departments). Research workflows (e.g., clinical trial data collection) naturally align with EMR interfaces. Hospital2 pediatric hospital reduced data processing time for growth hormone therapy studies via automated EMR data extraction.

(2) Researchers as super-users

Principal investigators often co-design EMR modules (e.g., custom analytics tools)

(3) Problem-driven upgrades

To address gene-EMR integration challenges, hospital2 built a multimodal data middleware, creating a “demand→development→feedback” loop.

4.2.8 Large-scale public hospitals often face greater peer and rating pressure

(1) Isomorphism

The digital transformation achievements of top-tier institutions like the Children's Hospital of Fudan University and Beijing Children’s Hospital (e.g., 90% coverage of AI-assisted diagnosis) have established "best practice" diffusion networks through industry conferences and academic journals, compelling peer hospitals to accelerate imitation. High-rated hospitals gain a 30% boost in search rankings on online medical platforms (e.g., Haodf.com), directly channeling patient traffic to digitally advanced institutions and creating a "Matthew Effect." Pediatricians with strong digital skills have become scarce resources. Their career mobility pressures hospitals to upgrade technological tools (e.g., deploying research data platforms) to retain talent.

(2) Technology adoption as an "arms race"

Diminishing Marginal Returns of Relative Advantage: When most regional hospitals achieve Electronic Medical Record (EMR) Level 5, top-tier hospitals like Hospital 5 must pursue Levels 6-7 to maintain differentiation. However, each level upgrade increases marginal costs by 40% (e.g., Level 7 requires natural language processing engines).

(3) Adaptive challenges under scale disadvantage

Pediatric departments in hospital5 share core systems (e.g., PACS imaging platforms) with dozens of departments. Any functional modification requires cross-departmental coordination, prolonging demand response cycles to 21 days. Legacy EMR vendors (e.g., Neusoft, Winning) create technological lock-ins due to prohibitive data migration costs (estimated at ¥120 million), hindering adoption of advanced cloud-native architectures. Under high rating pressures, hospitals opt for low-risk incremental improvements (e.g., EMR template optimization) over disruptive innovations (e.g., blockchain-based medical records), accumulating technological lag risks.

4.2.9 Smaller hospitals are more concerned about ROI

(1) Revenue-cost sensitivity model

Small-scale hospitals like Hospital6 prioritize cost-benefit ratios in digital transformation, strategically aligning IT investments with departmental revenue contributions and policy mandates. Hospital6 employs a quantifiable model to rank digitalization priorities across departments: Priority Score = 0.6 × (Revenue Contribution Rate) + 0.3 × (Policy Compliance Weight) + 0.1 × (Strategic Alignment)

Pediatrics, despite its high policy compliance weight (25%), scores lower than surgery due to its limited revenue contribution (8% vs. surgery’s 35%).

(2) External resource mobilization strategies

Public-Private Partnership (PPP) Model: Hospital6 partners with tech firms under revenue-sharing agreements: Tech companies cover upfront IT costs for pediatrics. The hospital pays usage-based fees (e.g., per AI diagnosis), converting fixed costs into variable expenses.

(3) Adaptive decision-making under resource constraints

Dynamic Priority Adjustment Mechanism like Real-Time Dashboard Monitoring. Key metrics (e.g., pediatric patient attrition rate, per-visit drug costs) are tracked via an operational dashboard. If patient attrition exceeds a certain extent due to outdated IT systems, system will automatically reallocated to pediatrics. Minimum Viable Product (MVP) Testing:

Hospital 6 adopted Low-cost SaaS tools (e.g., cloud-based subsystems) are piloted in pediatrics at ¥30,000/year, minimizing upfront risks while validating effectiveness. Modular Implementation Pathway , Phase 1: Core Functions (30% of costs): Deploy essential systems (e.g., EMR) to meet policy baselines. Phase 2: Value-Added Features (70% of costs): introduce advanced tools (e.g., AI-powered follow-ups) as pediatric revenue grows.

4.2.10 Differences between pediatric internal and surgery

(1) Age differences and adoption drivers: relative advantage and age-related perceptions

Younger Pediatric Surgeons: As "early adopters" (Sáenz-Royo et al., 2015), they more readily recognize the relative advantages of digital tools, such as postoperative follow-up systems that streamline data collection and reduce administrative tasks. For example, a tertiary hospital introduced an AI postoperative management platform in pediatric surgery, cutting follow-up response time by 25% and improving complication detection rates by 15%.

Senior Pediatric Internists: Often part of the "late majority," they perceive traditional methods (e.g., in-person consultations) as sufficient, while viewing digital tools as complex (e.g., multi-step workflows) and burdensome.

(2) Observability and postoperative scenario compatibility

Surgical outcomes (e.g., wound healing, functional recovery) are highly observable, allowing digital tools (e.g., rehabilitation progress apps) to demonstrate measurable benefits. For instance, hospital 1's pediatric surgery department achieved a parent satisfaction increase from 75% to 92% using a postoperative management system. Internal medicine's reliance on dynamic assessments (e.g., asthma exacerbations) limits the trialability of tools like AI diagnostics, as physicians require repeated validation of results, dampening adoption enthusiasm.

(3) Institutional theory perspective: departmental culture and institutional inertia

Surgery's Efficiency-Driven Culture and Institutional Flexibility: Pediatric surgery's institutional logic emphasizes quantifiable outcomes (e.g., surgical success rates, recovery timelines), aligning with the standardized nature of digital tools. For example, hospital1 integrated a postoperative complication alert system into performance evaluations, driving universal adoption. Isomorphic pressures (DiMaggio & Powell, 1983) push surgical departments to emulate industry leaders, such as the 15% annual growth in Da Vinci surgical robot adoption in pediatric surgery, compared to only 5% in internal medicine.

(4) Internal medicine's experience-based practices and path dependency

Pediatric internal medicine's long-standing institutional inertia prioritizes physician experience, as decisions depend on individual patient factors (e.g., allergy history, genetics). This fosters skepticism toward "black-box" algorithms in clinical decision support systems. Normative pressures (e.g., evidence-based guidelines) reinforce traditional workflows over digital reliance. Only 20% of internists use AI recommendations as primary references (M. Chen et al., 2022).

(5) CAS theory perspective: workflow compatibility

Postoperative Management's Standardized Compatibility: Surgical workflows (e.g., wound care, follow-up scheduling) are highly standardized, enabling seamless digital integration. Systems dynamically adapt (McLean et al., 2024) to optimize resource allocation, such as risk-based prioritization of postoperative follow-ups, minimizing redundant labor. Internal medicine deals with unstructured data (e.g., patient-reported symptoms, evolving physical signs), which existing systems struggle to synthesize. For example, a pediatric asthma management platform in hospital1 saw 70% abandonment due to failures in integrating lung function data with patient narratives. Systems attempting to accommodate internal medicine's needs often become overly complex, adding features (e.g., multi-disease modules) that further deter adoption. An AI cough analysis tool saw <20% usage among senior internists in hospital 2 due to high false positives (25%) and complex interfaces (8 clicks per report). Complexity exceeded tolerance thresholds, clashing with internal medicine's experience-centric culture.

4.3 Three-level coding and verification

4.3.1 Open coding

Open coding, the first step of this study, aims to gain a preliminary understanding of the data collected through in-depth interviews. We transformed the descriptions, viewpoints, and feedback from interview texts into conceptual labels, forming free nodes (or initial concepts). Our goal is to gather diverse data segments related to the differences in the digital maturity of pediatric hospitals, laying a foundation for subsequent axial and selective coding.

Using NVivo software, we divided and coded the interview texts to deeply understand the data. We analyzed numerous text segments, marked sentences related to factors influencing the digital maturity of hospitals, and generated 72 initial concepts. To ensure the universality and validity of these labels, we removed those mentioned only once and irrelevant to the research topic. Then, we merged with similar labels, resulting in 60 representative categories. Some coding examples are presented in Table 4.5.

Table 4.5 Open coding

Initial Category	Original Quotation	Theory Framework Alignment
High regard for digitization from hospital leaders	"I think our previous leaders were quite far-sighted. He was quite competent. When our new hospital district opened, he introduced the JCI certification."	Institutional Theory Leadership-driven institutional pressure: legitimacy pursuit, JCI compliance.
Information awareness and foresight of leaders	"Our hospital is at the forefront of digitization in Shenzhen and even Guangdong Province. The leadership has a deep understanding of the prospects and potential of digitization	Institutional Theory Executive-level institutional cognition: strategic alignment with digital norms
Direct promotion by top leaders	"Top - level leaders' strong promotion, such as incorporating digital initiatives into performance evaluations, yields different results."	Institutional Theory Coercive isomorphism: leadership mandates as institutional pressure
Shorter decision-making chains in non - affiliated hospitals	"Non - affiliated hospitals have shorter decision - making chains than affiliated ones, with faster responses and quicker feedback on other departmental needs."	AST/CAS Theory Organizational adaptability: decentralized structure enhancing system agility.
Multiple training levels for digital knowledge	"When deploying deep seek, there will be training for doctors, making it easier for them to accept."	Innovation Diffusion Theory Training reduces perceived complexity and accelerates adoption.
Simplification of decision-making processes and response speed	"From start to finish, it might take just one or two episodes to upgrade the entire decision-making process efficiently."	AST/CAS Theory Dynamic Process: Streamlined decision-making reflecting self-organizational capabilities.
Flexibility in temporary permission opening by the information department	"Therefore, they would have engineers assist in system integration, guiding us through the necessary steps."	AST/CAS Theory Agent Interaction: Collaboration between IT and clinical departments as adaptive agent synergy.
Rapid approval for non-funding-related projects by leadership	"Leaders provide quicker responses for information department projects that do not involve financial support."	Institutional Theory Institutional Flexibility: Rapid approval of non-financial projects reflecting policy elasticity.
Coordination mechanisms among different functional departments	"For example, as a laboratory, if we have any needs regarding the system, we can submit requests through the OA	AST/CAS Theory Cross-Agent Collaboration: Cross-departmental OA request mechanisms enhancing system connectivity.
Strong support from Shenzhen district finance for	"In reality, this initiative is closely tied to the hospital leadership's decisions rather than the district's policies."	Institutional Theory Resource Dependence: Local fiscal support

digitalization		as an institutional resource influencing transformation decisions.
Advantages of Nanshan District Hospital environment and digital construction	"When I visited Nanshan District People's Hospital, I noticed that despite being an affiliated hospital, its decision-making process is relatively short due to loose affiliations, strong leadership support, and substantial fiscal backing."	AST/CAS Theory, Environmental Adaptation: Lenient affiliation and fiscal support forming an adaptive ecosystem.
Innovation driven by market economy development in regions	"Regional positioning positively influences digital transformation, with economically developed areas having greater fiscal support and more digital talent reserves."	Innovation Diffusion Theory Market Environment: Resource endowments in economically developed regions accelerating innovation diffusion.
Competition and benchmarking among regional hospitals	This differs from the Healthy China initiative, which also emphasizes extensive digitalization." "For instance, my mother mentioned that Dr. said Guangzhou offers the longest maternity leave among units."	Innovation Diffusion Theory Competitive Pressure: Regional peer competition driving mimetic adoption.
Hospitals maintain scale and market position through digital efforts	"Large public hospitals like us often face significant peer pressure and rating pressures to maintain their industry status	Institutional Theory, Normative Isomorphism: Rating pressures driving organizations to maintain industry status.
Market-oriented regions like Shenzhen focus on building departmental IP and smart services	"Shenzhen, with its high marketization level, has begun emphasizing the creation of departmental IPs and providing intelligent services."	Innovation Diffusion Theory. Relative Advantage: IP development forming differentiated technological competitiveness.
Large-scale hospitals face rating pressures	"Many hospitals, including XX Medical University, feel pushed by rating pressures to advance their digital initiatives."	Institutional Theory. Regulatory Compliance: Rating systems as mandatory institutional requirements.
Pressure from Electronic Medical Record Level 7 evaluation	"It's surprising that they achieved Level 7 electronic medical records years ago, while others are still working on Level 5."	Innovation Diffusion Theory, Compatibility: Interoperability requirements driving system integration innovation.
Promotion driven by interoperability review requirements	"Electronic medical records, 5G smart services, and information systems contribute to higher rankings in healthcare."	Innovation Diffusion Theory Compatibility: Interoperability requirements driving system integration innovation.
Younger patient demographics in pediatric hospitals	"Since we don't have as many patients, we started early on implementing smart cabinets, which are currently in use."	Innovation Diffusion Theory User Characteristics: Younger patient demographics lowering technology adoption barriers.
Higher acceptance of digital services among young	"Pediatric hospitals have higher ratings because their patient base consists of younger parents who were more open to digital innovations ten years	Innovation Diffusion Theory Compatibility: User digital literacy matching

parents	ago."	technological characteristics.
Proficiency in smartphone usage among parents of pediatric patients	"Considering our clientele, most parents now use mobile apps proficiently, regardless of age."	Innovation Diffusion Theory, Observability: Mobile app usage habits accelerating technology diffusion.
Crisis value warning system demand drives system construction	"The crisis value warning system is strictly regulated in foreign healthcare systems as a critical hospital	Institutional Theory International Norm Pressure: Adoption of foreign institutional standards.
Multi-disciplinary consultation information interaction needs	"For instance, a child requiring both dermatology and psychological consultations necessitates coordination between departments."	AST/CAS Theory System Emergence: Cross-disciplinary collaboration needs driving information system integration.
Clear referral pathways in pediatric tiered care	"Cross-departmental cooperation is better managed in our hospital."	AST/CAS Theory Hierarchical Adaptability: Optimized tiered care processes reflecting system structural resilience.
Patient sensitivity to waiting times	"Patients typically need to wait 40 to 50 minutes, with a waiting time of about half an hour. If the preceding patient takes longer, the waiting time may extend, causing dissatisfaction."	Innovation Diffusion Theory Result Demonstrability: manifest need for waiting time optimization.
Impact of patient satisfaction feedback on system improvements	“"Patients pay attention to the usability of systems such as appointment registration, post-examination procedures, and refund handling, all of which influence overall satisfaction."	AST/CAS Theory Feedback Mechanism: Patient satisfaction driving system iteration.
Convenience requirements for WeChat-based appointment systems	"We found the current order sequence inconvenient for users, so we adjusted it to."	Innovation Diffusion Theory Complexity: Interface optimization reducing usage difficulty.
Higher proportion of older doctors in pediatric internal medicine	"There seems to be a higher proportion of older doctors in internal medicine departments."	AST/CAS Theory Organizational Inertia: Age structure influencing technology adoption speed.
Relatively younger age structure in pediatric surgery	"Pediatric surgeons tend to be younger and more receptive to new technologies due to"	AST/CAS Theory Adaptive Agents: Younger medical staff as innovation adopters.
Variability in doctor acceptance of new systems	"Older doctors find it challenging to adapt to new systems due to difficulties with typing, whereas younger doctors are more open to adopting new technologies."	Innovation Diffusion Theory Adopter Categories: Differentiation between early adopters and late majority.
Immediate visible outcomes in pediatric surgery	"Pediatric surgery benefits from immediate results, leading to greater adoption of digital tools post-operation."	Innovation Diffusion Theory Observability: Immediate postoperative

		results promoting technology adoption.
Digital applications in pediatric internal medicine diagnosis and treatment	"Digital tools are predominantly used during the diagnostic and treatment processes in pediatric internal medicine."	Innovation Diffusion Theory Technical-Task Fit: Diagnostic process digitization improving efficiency.
Postoperative management focus in pediatric surgery	"Pediatric surgeons experience immediate treatment effects, whereas internal medicine doctors face ongoing patient discomfort and parental anxiety, affecting their satisfaction with technological solutions."	AST/CAS Theory Dynamic Balance: Divergent departmental needs driving system differentiation.
Efficiency of liaison officer training models	"Each department selects a young and capable liaison officer, who receives initial training from the information department before disseminating knowledge within their respective departments."	Innovation Diffusion Theory Opinion Leaders: Liaison officers as internal diffusion nodes.
Internal dissemination of digital knowledge within departments	"Training sessions lasting ten minutes each day are held to educate staff on various digital tools and practices."	Innovation Diffusion Theory Internal Diffusion: Daily training enhancing knowledge penetration.
Transition strategies between old and new systems	The hospital adopted a strategy of 'old methods for old systems, new methods for new systems,' but with evolving technology and evaluation requirements, doctors must now master new digital skills."	AST/CAS Theory Adaptive Threshold: Transition between old and new systems reflecting organizational learning.
Earlier digital initiatives in private hospitals compared to public ones	"Private hospitals utilize enterprise WeChat tools for managing work records and case files,	Institutional Theory Organizational Type Variation: Market-driven institutional choices in private hospitals.
Private Hospitals Emphasize Patient Privacy Protection	"But under the new system in China, it also respects privacy, but it does not prioritize personal privacy as a critical factor. Here, patient privacy is the top priority, and we enforce it very strictly."	Institutional Theory Normative Pressure: Privacy protection as a special industry institutional requirement.
More Refined System Design in Private Hospitals	"The systems in private hospitals are often developed by their own engineering teams, including appointment systems and HIS (Hospital Information System). These systems provide detailed medical records, examination reports, and cost information. Private hospitals are more meticulous in terms of digitalization."	AST/CAS Theory Autonomous Development: In-house teams enhancing system adaptability.
Complexity of Integrating with Medical Insurance Systems	"Nowadays, it's quite similar to the Chinese system at the fundamental level. However, there are differences in the upper layers, such as case descriptions, appointment systems, and connections with financial departments. When the purposes differ slightly, there will still be some discrepancies. Since these two systems are not integrated, many international hospitals find it extremely difficult to integrate with the	Institutional Theory Coercive Barriers: Institutional and technical gaps in medical insurance interfaces.

	medical insurance system, equivalent to installing an additional system."	
Challenges in Data Exchange Between Private Hospitals and Government Systems	"There are differences in the interfaces for integrating international hospitals with the medical insurance system. Additionally, they place greater emphasis on protecting patient privacy, thus tending to develop personalized medical services like crisis value management and follow-up teams."	AST/CAS Theory System Fragility: Heterogeneous system interactions highlight ecological adaptability gaps.
Differences Between International and Localized Systems	"This kind of pressure is significant, especially for foreign capital hospitals, which face considerable regulatory pressure."	Institutional Theory Cross-Institutional Conflict: Regulatory differences between Chinese and international norms causing compliance pressures.
Building Personalized Follow-Up Teams in Private Hospitals	"Here, we have established a follow-up team specifically for each individual. This is called SRM, where we have coordinators that you wouldn't find in public hospitals, known as K coordinators."	Innovation Diffusion Theory Personalized Service: Differentiated innovations form competitive advantages.
Establishment of Crisis Value Management Systems	"We created an external mini program that triggers alerts if a patient visits multiple departments within three months. We added conditions, such as visits to different departments, and when certain criteria are met, we classify it as a crisis value management situation and start issuing warnings."	AST/CAS Theory Early Warning Mechanism: Dynamic monitoring reflecting system self-adaptation.
Achieving Full Paperless Operations	"We've been practicing full paperless operations for 20 years. During this period, China's localized digital management has made significant progress, particularly in the last decade."	Institutional Theory Institutional Evolution: Long-term compliance accumulating institutional advantages.
Structural Requirements for Medical Records in Research Projects	"One aspect is the need for research. For example, the level of electronic medical records requires structured data, ensuring that specific content is included in the system."	Innovation Diffusion Theory Research-Driven: Research needs improving data structuring levels.
Impact of Research Data Extraction on System Design	"To ensure researchers can obtain relevant information, such as whether a patient has abdominal pain or other symptoms, the system must include these details. If not specified, doctors may overlook them."	AST/CAS Theory Data Governance: Research needs guiding system functional design.
Integration of Sample Banks and Informed Consent for Research	"We have integrated informed consent for research into our registration system by directly communicating with the IT department. This makes the entire hospital a responsive system, facilitating various tasks."	AST/CAS Theory Cross-System Integration: Synergetic evolution of research processes and clinical systems.
Size and Expertise of IT Teams	Our hospital's IT team in Shenzhen currently feels adequate, with around 20 people, which is relatively large compared to other major hospitals."	AST/CAS Theory Resource Capacity: IT team size influencing system maintenance capabilities.

Advantages of Hospital-Developed Teams	"Our hospital might be slightly better than others because we have a development team, although not comparable to companies. However, we can handle basic needs within the hospital."	Innovation Diffusion Theory Technical Autonomy: In-house development accelerating demand response.
Talent Development and Renewal	"In response to rapid technological advancements, we continuously bring in fresh talent to stay current."	AST/CAS Theory Organizational Learning: Talent renewal maintaining system adaptability.
Alignment Between Insurance Companies and Evidence-Based Medicine	"Evidence-based medicine requires all examinations and treatments to be evidence-supported to avoid over-testing, over-treatment, and over-medication. Public hospitals often lack oversight in these areas, whereas insurance companies align with evidence-based medicine to reduce claims."	Institutional Theory Third-Party Institutional Pressure: Insurance agencies promoting evidence-based medical norms.
Doctor-Led Demand Proposals in Specialized Clinics	"Local pediatric clinics, relying on insurance, adhere to evidence-based medicine, minimizing unnecessary tests and preventing over-treatment. They are centered around influential doctors who propose IT requirements."	Innovation Diffusion Theory Opinion Leaders: Doctors as innovation demand initiators.
System Design to Prevent Over-Treatment	"For instance, targeted testing includes over 100 pathogens, with over 50% of patients receiving orders daily, which is considered over-treatment."	AST/CAS Theory Negative Feedback Mechanism: System design curbing overtreatment.
Speed of System Response Mechanisms	"At the very least, I think the response mechanism is quite fast. Any issues can be promptly addressed."	AST/CAS Theory Response Efficiency: Rapid fault handling reflects system resilience.
Network Load During Peak Hours	"The biggest issue is network load due to frequent updates, causing slower internet speeds during peak hours."	AST/CAS Theory System Bottleneck: Peak loads exposing infrastructure adaptability gaps.
System Stability and Data Security	"Hospitals have backup systems to handle potential system failures, ensuring each department can continue working normally."	AST/CAS Theory Redundancy Design: Backup mechanisms enhancing system disturbance resistance.
Small-Scale Hospitals Focus on ROI of Digital Investments	"Our smaller hospitals pay more attention to the return on investment from digitalization."	Innovation Diffusion Theory Cost-Benefit Analysis: ROI-oriented adoption decisions.
Enhancement of Work Efficiency Through Digital Systems	"In practice, the impact is not significant." "Without the previous model, it would be impossible to manage the current workload."	Innovation Diffusion Theory Perceived Usefulness: Digitization as indispensable business infrastructure.
Balancing Cost Control and Service Quality	"If it's my money, I would definitely push for improvements. However, in public hospitals, the funds come from the government, so the motivation might be less."	Institutional Theory Ownership Variation: Investment motivation differences between public and private hospitals.

Infrastructure Development	"One, the completeness of infrastructure development. For example, ensuring that all departments have access to high-speed internet and reliable hardware is crucial for maintaining operational efficiency."	AST/CAS Theory Infrastructure Resources: Network and hardware as foundational elements for system evolution.
Investment in Hardware Such as Data Centers, Networks, and Storage	"With these foundational elements in place, improvements can be made."	AST/CAS Theory Underlying Architecture: Hardware investment determining system scalability.
Data Governance Capabilities and Utilization Levels	"Another critical factor is our data governance capability. Despite having a large volume of data, without effective governance, the overall utilization of this data remains low."	AST/CAS Theory Data Ecosystem: Governance capabilities determining data resource value conversion.

4.3.2 Axial coding

In this study, the open coding phase generated a series of initial concepts related to various aspects of digital maturity differences in pediatric hospitals. Although these concepts have theoretical value, they remain isolated and lack interconnection. To better understand the relationships between these concepts, we conducted axial coding.

Axial coding, as the second phase of the research, builds on the foundation of open coding to further organize and classify data, clarifying the core themes and main concepts of the study. Axial coding helps integrate a large amount of open coding into more organized information, facilitating a deeper understanding of the intrinsic connections within the data on digital maturity differences in pediatric hospitals. The goal of axial coding in our study was to consolidate the information from open coding into major categories for more in-depth analysis and discussion of the structural dimensions affecting digital maturity differences in pediatric hospitals. Through axial coding, we consolidated 72 initial categories into 24 main categories, which were ultimately summarized into 7 core categories: Leadership Decision Factors, Regional Economic Factors, User Characteristics Factors, Organizational Culture Factors, Operational Model Factors, Business Demand Factors, and Technical Investment Factors, as shown in Table 4.6.

Table 4.6 Axial coding

Initial Categories	Theoretical dimension	Main Categories	Core Categories
High emphasis on digitalization by hospital leaders	Institutional Theory - Institutional pressure	Leadership drive	Leadership decision factors
Awareness and foresight of hospital leaders on IT	Institutional Theory - Institutional cognition		
Hospital president personally oversees digitalization and incorporates it into evaluations	Institutional Theory - Coercive isomorphism		
Shorter decision-making chain in non-affiliated hospitals	AST/CAS Theory - Organizational adaptability	Decision efficiency	
Multi-layered decision-making in affiliated hospitals for teaching and research	AST/CAS Theory - System dynamics		
Simplification and responsiveness of decision-making processes	AST/CAS Theory - Adaptive feedback		
Flexibility in granting temporary access permissions by IT department	AST/CAS Theory Agent interaction	Management flexibility	
Rapid approval of non-funding support projects by leadership	Institutional Theory - Regulatory flexibility		
Coordination mechanisms among different functional departments	AST/CAS Theory - Cross-agent collaboration		
Strong financial support from Shenzhen district for digitalization	Innovation Diffusion Theory - Market environment	Location advantages	Regional economic factors
Advantages of XX District hospital environment and digital construction	AST/CAS Theory - Environmental adaptation		
Innovation driven by developed market economies	Innovation Diffusion Theory - Relative advantage		
Competition and benchmarking among regional hospitals Market pressure	Innovation Diffusion Theory - Competitive pressure	Market pressure	
Hospital size and market position maintenance needs	Institutional Theory - Normative isomorphism		
High degree of marketization in Shenzhen promotes IP building in departments	Innovation Diffusion Theory - Result demonstrability		
Large-scale hospitals face rating pressures Rating-driven	Institutional Theory - Standardization pressure	Rating-driven	
Pressure of EMR Level 7 evaluation	Institutional Theory - Coercive pressure		
Promotion driven by interoperability evaluation requirements	Innovation Diffusion Theory - Compatibility		
Young patient demographics in pediatric hospitals	Innovation Diffusion Theory - User characteristics	Patient characteristics	User characteristics factors
High acceptance of digital services by young parents	Innovation Diffusion Theory - Compatibility		
Proficiency in using smartphones by parents of pediatric patients	Innovation Diffusion Theory - Observability		
System development driven by crisis value warning needs	AST/CAS Theory - System requirements	Clinical special needs	Organizational culture factors
Information exchange needs for multi-disciplinary consultations	AST/CAS Theory - Emergent behavior		
Clear referral needs in pediatric tiered diagnosis and treatment	AST/CAS Theory - Hierarchical adaptability		

Sensitivity of patients to waiting times	Innovation Diffusion Theory - Perceived usefulness	Service experience demands	
Impact of patient satisfaction feedback on systems	AST/CAS Theory - Feedback mechanism		
Convenience requirements for WeChat appointment system usage	Innovation Diffusion Theory - Perceived ease of use		
High proportion of older doctors in pediatric internal	AST/CAS Theory - Organizational inertia	Medical staff characteristics	
Relatively younger age structure of pediatric surgeons	AST/CAS Theory - Adaptive agents		
Differences in acceptance of new systems by doctor	Innovation Diffusion Theory - Adopter categories		
Immediate effects of pediatric surgeries	Innovation Diffusion Theory - Observability	Discipline characteristics	
Digital applications in pediatric internal medicine diagnosis and treatment process	AST/CAS Theory - Technical-task fit		
Digital use mainly for postoperative management in pediatric surgery	AST/CAS Theory - Dynamic balance		
Efficiency of liaison officer training models	Innovation Diffusion Theory - Diffusion channels	Training mechanisms	
Internal dissemination of digital knowledge within departments	Innovation Diffusion Theory - Knowledge dissemination		
Transition strategies between old and new systems	AST/CAS Theory - Adaptive threshold		
Private hospitals started earlier than public hospitals	Institutional Theory - Organizational type variation	Hospital type differences	Operational model factors
Emphasis on patient privacy protection by private hospitals	Institutional Theory - Normative pressure		
More refined system design in private hospitals	AST/CAS Theory - Autonomous development		
Complexity of integrating with medical insurance systems	Institutional Theory - Coercive barriers	Interface challenges	
Difficulties in data exchange between private hospitals and government systems	AST/CAS Theory - System fragility		
Differences between international and localized systems	Institutional Theory - Cross-institutional conflict		
Personalized follow-up team building in private hospitals	Innovation Diffusion Theory - Personalized innovation	Differentiated services	
Establishment of crisis value management systems	AST/CAS Theory - Early warning mechanism		
Achievement of full paperless operations	Institutional Theory - Institutional evolution		
Structured requirements for electronic medical records in research projects	Innovation Diffusion Theory - Research needs	Research-driven	Business demand factors
Impact of research data extraction on system design	AST/CAS Theory - Data governance		
Integration of sample banks and informed consent for research	AST/CAS Theory - System integration		
Size and professionalism of IT teams	AST/CAS Theory - Resource capacity	Technical capability	
Advantages of hospital-developed teams	Innovation Diffusion Theory - Technical autonomy		

Talent development and renewal	AST/CAS Theory - Organizational learning		
Alignment between insurance companies and evidence-based medicine	Institutional Theory - Third-party pressure	Innovation in healthcare models	
Doctor-led demand proposals in specialized clinics	Innovation Diffusion Theory - Opinion leaders		
System design to prevent over-treatment	AST/CAS Theory - Negative feedback		
Speed of system response mechanisms	AST/CAS Theory - Response efficiency	System performance	Technical investment factors
Network load capacity during peak hours	AST/CAS Theory - System bottleneck		
System stability and data security	AST/CAS Theory - Redundancy design		
Small-scale hospitals focus on ROI of digital investments	Innovation Diffusion Theory - Cost-benefit analysis	Investment benefits	
Enhancement of work efficiency through digital systems	Innovation Diffusion Theory - Perceived usefulness		
Balancing cost control and service quality	Institutional Theory - Ownership variation		
Completeness of infrastructure development	AST/CAS Theory - Infrastructure resources	Technical foundation	
Investment in hardware such as data centers, networks, and storage	AST/CAS Theory - Underlying architecture		
Data governance capabilities and utilization	AST/CAS Theory - Data ecosystem		

4.3.3 Selective coding

In this study, the process of selective coding involved integrating the main categories derived from axial coding—factors influencing digital maturity differences in pediatric hospitals—into a comprehensive theoretical framework. This framework aims to deepen our understanding of the factors influencing digital maturity differences in pediatric hospitals and their interactions. Simultaneously, the core objective during selective coding was to construct a theoretical framework that elucidates the interactions between the core category—digital maturity differences in pediatric hospitals—and other categories. Below is a typical relational structure table based on the main categories. Table 4.7 illustrates the relational structure, structural connotations, and corresponding examples among the main categories.

Table 4.7 Selective coding

Relational Structure	Structural Connotations	Theoretical Dimension
Leadership drive → Digital maturity	All public hospitals emphasize that leadership emphasis is the most important driving factor for digital transformation and innovation diffusion. Direct involvement of top leadership in digital initiatives significantly increases maturity.	Institutional Theory - Institutional pressure
Decision efficiency → Speed of digital implementation	Non-affiliated hospitals have shorter decision-making chains compared to affiliated hospitals, resulting in faster responses. The IT department's response speed to other departments' needs is also quicker.	AST/CAS Theory - Organizational adaptability
Location advantages → Resource investment	In regions with well-developed market economies and greater financial support, there are more digital talents and better infrastructure.	Innovation Diffusion Theory - Market environment
Rating-driven → Digital investment preferences	Large-scale public hospitals often face greater peer pressure and rating pressures to maintain their industry status and competitiveness, leading to higher digital investments.	Institutional Theory - Normative isomorphism
Patient characteristics → Acceptance of digital services	Women and children's specialty hospitals tend to have higher ratings because their patient demographics are relatively younger, consisting mainly of young parents who have a high acceptance of digital services.	Innovation Diffusion Theory - User characteristics
Innovation in healthcare models → Choice of digital direction	Private hospitals and clinics are more inclined to develop personalized medical services, such as crisis value management and follow-up teams, driven by evidence-based medicine-oriented digital needs.	Innovation Diffusion Theory - Relative advantage
Medical staff characteristics → Speed of system adoption	Speed of system adoption Pediatric internal medicine has more older doctors who are relatively less accepting of digital systems, while pediatric surgeons are generally younger and more accepting.	AST/CAS Theory - Adaptive agents
Discipline characteristics →	Digital applications in pediatric surgery are mostly used for postoperative management,	AST/CAS Theory - Technical-task fit

Digital application scenarios	whereas digital tools in pediatric internal medicine are more commonly applied during the diagnostic and treatment process.	
Hospital type differences → Digital focus	Private hospitals place greater emphasis on patient privacy protection, while public hospitals focus more on integrating with medical insurance systems and meeting rating standards.	Institutional Theory - Organizational type variation
Interface challenges → System integration difficulty	The complexity of integrating different hospital systems with medical insurance systems affects overall digital maturity.	Institutional Theory - Coercive barriers
Research-driven → Structured level	Hospitals with more research tasks positively promote digitalization, as research requires high levels of structured electronic medical records.	Innovation Diffusion Theory - Research needs
Technical capability → Self-developed system capability	The size and professionalism of the hospital's IT team directly impact the ability to develop and maintain systems.	AST/CAS Theory - Resource capacity
Investment benefits → Decision-making in small-scale hospitals	Smaller hospitals pay more attention to the return on investment (ROI) of digital initiatives, which influences their digital progress.	Innovation Diffusion Theory - Cost-benefit analysis

4.3.4 Theory saturation verification

In this study, we conducted a detailed analysis of the issues surrounding digital maturity differences in pediatric hospitals, exploring the underlying causes and their potential impacts on hospital development. To achieve theoretical saturation, we took a series of steps to ensure the completeness and depth of our research. Theoretical saturation is reached when new data no longer alters the theoretical framework developed during the research process; that is, new information does not introduce new concepts or categories, and existing concepts and categories are consistently validated by new data. Achieving theoretical saturation indicates that the understanding of the phenomenon at the current stage is relatively complete, and no additional data is needed to supplement the existing theoretical framework.

In the initial phase of the study, we systematically collected a large amount of preliminary data on digital maturity differences in pediatric hospitals and their influencing factors. Through open coding, we identified a series of initial concepts and categories covering multiple dimensions, from leadership emphasis to regional economics, from user characteristics to organizational culture. As the research progressed, we continued to collect data and repeatedly tested and validated these preliminary concepts and categories. To ensure the depth and breadth of the theory, we constantly reviewed and compared data collected in early and later stages to verify the stability and consistency of these concepts and categories. During this process, some initial concepts were further refined or merged to more accurately reflect the issues and complexities inherent in digital maturity differences in pediatric hospitals. Simultaneously, we also monitored whether new data introduced new perspectives or concepts to ensure the comprehensiveness of the research. When the data collected consecutively began to repeat and no longer provided new insights into the existing theoretical framework, we considered that theoretical saturation had been achieved.

4.3.5 Theory building

Building upon the three-level coding process and the fsQCA analysis, this study synthesizes a comprehensive theoretical framework to explain the mechanisms underlying differences in digital maturity across pediatric hospitals. The framework, illustrated in Figure 4.1, integrates insights from Innovation Diffusion Theory, Institutional Theory, and Complex Adaptive Systems (CAS) Theory, reflecting the multi-faceted nature of digital transformation.

This theoretical model is anchored in a dynamic, configurational lens. Instead of framing digital maturity as a linear result stemming from isolated factors, the framework defines it as an emergent characteristic shaped by the interaction between five antecedent conditions: organizational leadership and operational models, regional economic and technological resources, user attributes, business requirements, and organizational culture. These elements do not function in isolation; rather, they form distinct, synergistic configurations， referred to as pathways， that propel hospitals toward a high level of digital maturity.

The fsQCA findings identify seven such pathways, each serving as a distinct formula for achieving success. For instance, the User Characteristics-Driven pathway shows that strong demand from digitally literate young parents can drive digital transformation， even in the absence of strong leadership or abundant resources. By contrast, the Leadership-Economic & Technological Dual-Driven pathway illustrates that dedicated leadership, paired with significant investment, can lead to digital maturity regardless of other conditions. These pathways underscore the principle of equifinality: different configurations of conditions can yield the same end result.

Central to the framework is the concept of the *adaptive threshold*, derived from CAS theory. This threshold represents the minimum level of organizational readiness and resource alignment required for digital initiatives to gain traction and avoid systemic friction. For example, technological investments must be matched by corresponding adaptations in workflows, staff competencies, and cultural norms to be effective. The model emphasizes that transformation is not merely about adopting technology but about achieving a dynamic balance between external pressures, internal capabilities, and evolving user expectations.

This theoretical contribution moves beyond existing models by offering a holistic, context-sensitive explanation of digital maturity. It provides a foundation for understanding how pediatric hospitals can navigate their unique challenges and opportunities in the digital age, offering both theoretical insights and practical guidance for researchers and practitioners alike，as illustrated in Figure 4.1

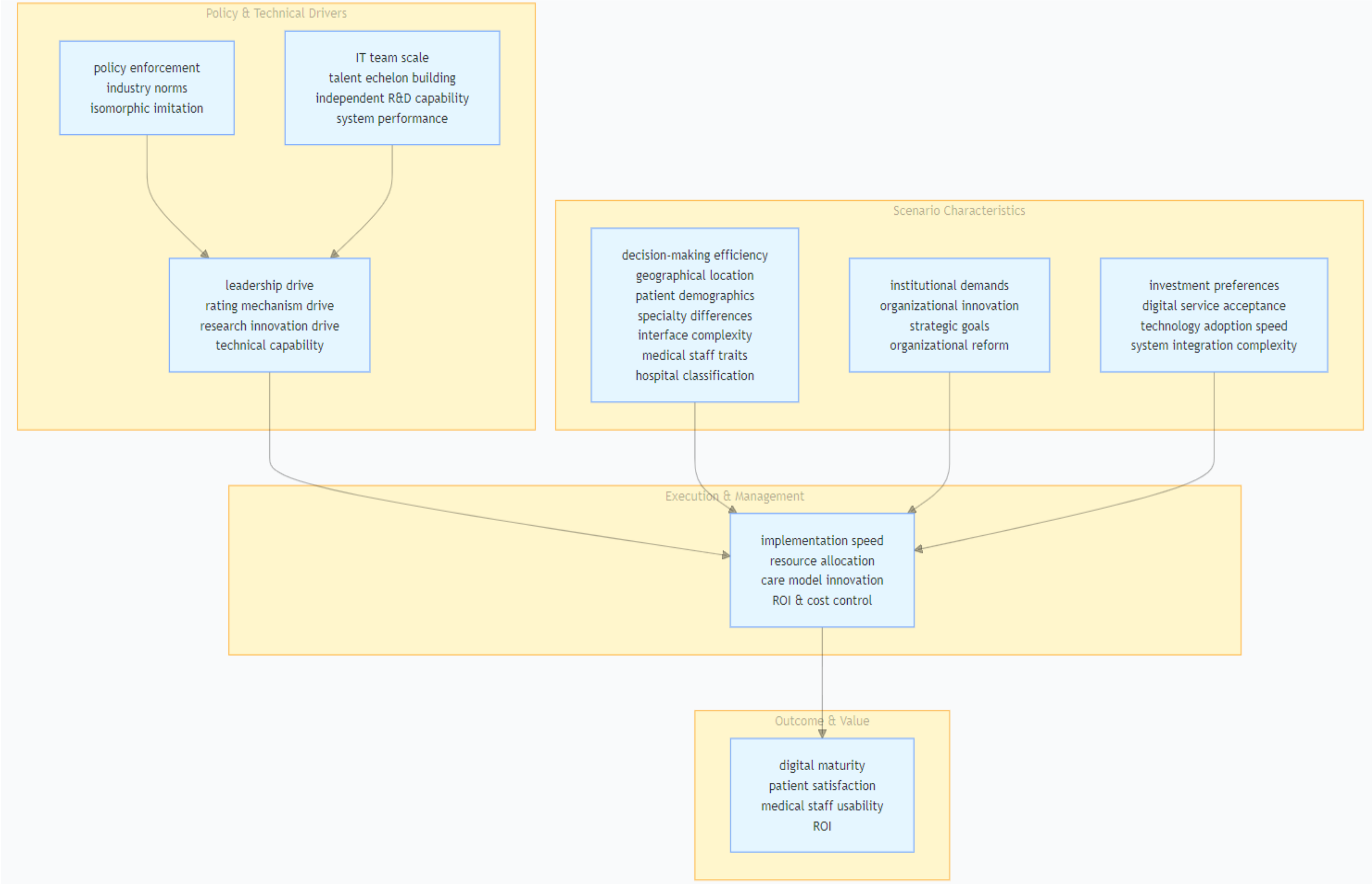

Figure 4.1 Theoretical framework for the formation mechanism of digital maturity differences in pediatric hospitals

4.4 fsQCA

After completing the three-level coding to construct seven core categories, this study employs fuzzy-set qualitative comparative analysis (fsQCA) to explore the complex causal mechanisms of digital maturity in pediatric hospitals.

4.4.1 The necessity of selecting fsQCA

(1) Transcending single causality and revealing configurational effects

Digital maturity is the result of multi-factor synergy (e.g., leadership emphasis needs to be combined with regional resources and technical capabilities). Traditional methods struggle to capture "concurrent multi-causality" or "substitutional equivalence" relationships (e.g., private hospitals achieve maturity improvement through the combination of "privacy protection + personalized services"). Through configurational analysis, fsQCA can identify the synergistic impacts of different factor combinations, aligning with the logic in complex systems theory that "interactions among multiple modules determine overall performance."

(2) Adaptability to the characteristics of small-to-medium samples

This study conducted interviews with 43 personnel from 6 hospitals, constituting a small-to-medium-scale dataset. Based on the ideology of set theory, fsQCA is suitable for analyzing asymmetric relationships in small-to-medium samples (e.g., the offsetting effect of "high demand + low resources"), avoiding the sample size limitations of regression analysis.

(3) Qualitative-quantitative integration to strengthen theoretical verification

The three-level coding has already extracted seven core categories (leadership decision-making, regional economy, etc.). fsQCA can transform these into quantitative sets to verify the hypothesis in the theoretical framework of "factor combinations → maturity" (e.g., the configurational effect of "leadership-driven + high acceptance" in innovation diffusion theory), achieving complementarity between theory and data.

4.4.2 The rationality of merging antecedent variables

(1) Theory-Driven Variable Simplification

Based on the results of three-level coding and combined with three theoretical logics, this study merges seven core categories into five antecedent variables:

Institutional Response Capacity (leadership decision-making + operational model):

Leadership drive implements institutional pressures (e.g., rating compliance) through decision-making efficiency and hospital-type differences, aligning with the transmission mechanism of institutional theory ("authority logic → organizational behaviour").

Resource-Capability Composite System (regional economy + technological investment): Regional economy provides financial and talent resources, while technological investment transforms into system development capabilities, consistent with the "environment-technology compatibility" hypothesis of innovation diffusion theory.

Demand-Innovation Adaptation Module (user characteristics + business needs): Young parents' high acceptance and personalized service innovations (e.g., general practice critical value management) in the demand adaptation module conform to the "need → adoption" logic of the technology acceptance model.

Internal Adaptation Capacity (organizational culture): The age structure of medical staff and disciplinary characteristics directly affect system adoption speed (e.g., high acceptance among young doctors in pediatric surgery), independently reflecting "individual differences" in innovation diffusion.

(2) Methodological Configurational Simplification

fsQCA requires a reasonable match between the number of variables and sample size (typically ≤ sample size/2). With 6 hospitals and 43 interviewees as the research objects, retaining 7 variables would result in 128 logical configurations, while merging into 5 variables reduces this to 32 configurations. This avoids the "curse of dimensionality" and focuses on the interaction of core theoretical dimensions (e.g., the disadvantageous configuration of "weak institutional response + low resource capacity").

4.4.3 Basis for selecting six-value fuzzy set scoring

(1) Balancing Detail and Abstraction for Theoretical Adaptation

The six-value scale (0, 0.2, 0.4, 0.6, 0.8, 1) reflects the stages of maturity (e.g., 0.2 for "basic informatization," 1 for "full-process intelligence") and intensity differences in antecedent variables (e.g., "leadership drive" ranges from "occasionally mentioned" to "top priority project," corresponding to 0.2–1), aligning with the "adoption stages" division in innovation diffusion theory.

(2) Quantifying Institutional Pressures and Synergy Levels

Institutional pressures (e.g., rating evaluations) and system synergy (e.g., demand-resource matching) are continuous. Six-value scoring distinguishes pressure levels (e.g., 0.6 for "facing level 5 evaluation," 1 for "requiring level 7 evaluation") and quantifies the overall membership of configurations through fuzzy set operations to identify sufficient conditions for "high synergy configuration → high maturity."

(3) Data Operability

Qualitative information from interview texts (e.g., "frequency of leadership emphasis," "financial support intensity"), combined with expert scoring, converts qualitative evaluations into six-value scales, ensuring scoring processes align with data reality and theoretical logic.

(4) Summary: Coherence of Analytical Logic

After constructing the "seven categories → five variables" framework through three-level coding, fsQCA serves as a bridge between qualitative theory and quantitative verification: variable merging is based on the intersecting logics of innovation diffusion, institutional theory, and complex systems theory; six-value scoring adapts to research data characteristics and theoretical hypotheses; and finally, configurational analysis identifies key driving paths for digital maturity in pediatric hospitals, providing theoretical support for differentiated transformation.

4.4.4 Assignment rules and example table for five antecedent variables

After constructing the "seven categories → five variables" framework through three-level coding, fsQCA serves as a bridge between qualitative theory and quantitative verification: variable merging is based on the intersecting logics of innovation diffusion, institutional theory, and complex systems theory; six-value scoring adapts to research data characteristics and theoretical hypotheses; and finally, configurational analysis identifies key driving paths for digital maturity in pediatric hospitals, providing theoretical support for differentiated transformation, as shown in Table 4.8.

Table 4.8 Assignment rules

Antecedent Variable	Assignment Basis (Based on Interview Texts)	Fuzzy Value	Example Description	Theoretical Dimension
Institution-Operational Synergy System	Leadership decision strength (top leader promotion / inclusion in performance evaluation) + operational model efficiency (decision-making chain length / characteristics of private hospitals) Dean includes digital transformation in performance evaluation + non-affiliated hospital (short decision-making chain) + private hospital independently develops encryption system (e.g., Hospital2's "internet-based informed consent") Aggregation of resources lowers adoption thresholds	1	Dean includes digital transformation in performance evaluation + non-affiliated hospital (short decision-making chain) + private hospital independently develops encryption system (e.g., Hospital2's "internet-based informed consent")	Institutional Theory: Leadership commitment aligns with policy compliance (e.g., EMR digitization) CAS: Short decision chain enhances system flexibility
	Leadership support but not "top leader-led" + public hospital affiliation (longer decision-making chain) + reliance on external system deployment	0.4	Vice president in charge + tertiary first-class affiliated hospital (multi-layer approval required) + uses HIS system unified by Health Commission (e.g., Hospital5's 3-tier approval process for IT projects	Institutional Theory: Coercive isomorphism under public hospital affiliation CAS: Rigid structure causes slow response
Regional - Technical Composite Resources	No leadership attention + public grassroots hospital (no independent decision-making power) + paper-based operation	0	Leadership does not mention digitization + community health service center (no independent decision-making power) + manual medical records	Institutional Theory: Lack of institutional pressure CAS: System rigidity (no digital adaptation)
	Regional economic level (financial investment / talent reserve) + technical investment intensity (hardware / self-developed capability)	1	Shenzhen Nanshan District (strong finance + abundant digital talent) + 20-person self-developed team + full-process paperless system (e.g., Hospital1's collaboration with Tencent and Huawei)	Environmental (Hospital digital transformation): Regional digital infrastructure Resource (IDT): Technical resources and knowledge reserve
	Second-tier city (medium finance + small amount of technical talent) + outsourced development system + traditional computer room (occasional failures)	0.4	Second-tier city + outsourced development system + traditional computer room (occasional	Environmental (IDT): Moderate market conditions and policy

			failures) + annual financial investment of 10 million RMB (e.g., Hospital6's SaaS tool pilot in pediatrics)	environment Resource (CAS): Limited digital knowledge reserve
	Economically underdeveloped county (no special budget) + no technical team + uses stand-alone registration software	0	Located in a national poverty-stricken county + no digitization budget + manual registration and charging	Environmental (CAS): Background uncertainty (lack of resources) Resource: No digital resource readiness
User Characteristics	Proportion of young parents (<40 years old) + digital service utilization rate (WeChat registration / online feedback frequency)	1	Proportion of young parents: 95% + WeChat registration proportion: 90% + average 30 online suggestions per month	Innovation Diffusion Theory: User compatibility (digital-native parents) Moderators1 (IDT): Patient demand and organizational acceptance
	Proportion of young parents: 60% + balanced online and offline utilization + quarterly feedback on system problems	0.6	Patient age structure tends to be middle-aged + intelligent guide diagnosis utilization rate: 50% + proposes 1 system optimization requirement per quarter	Innovation Diffusion Theory: Moderate perceived usefulness and ease of use Moderators2 (IDT): Communication channels (occasional feedback)
	Mainly elderly family members (proportion of >60 years old: 80%) + 100% dependence on on-site services	0	Rural hospital + 100% on-site registration and payment + no online service records	Innovation Diffusion Theory: Low adoption due to age-related habit resistance Moderators1: Passenger flow (elderly-dominated)
Business Needs	Level of scientific research projects (national / provincial) + complexity of clinical processes (multidisciplinary consultation / referral frequency)	1	Undertakes national scientific research projects + 20 cases of cross-departmental consultations per week + high-frequency referral needs (e.g., pediatric critical care referral)	Innovation (Hospital digital transformation): Digital technology for research Process (CAS): Implement-interaction-coordinate feedback (EMR-data integration)

	No scientific research projects + less than 5 consultations per month + mainly basic diagnosis and treatment	0.2	Pediatric department of county-level hospital + only handles common diseases + no hospitalization or consultation needs	Innovation (IDT): Lack of relative advantage (no tech-driven research) Process: Limited digitalization stage (basic digitization)
	Single department service (e.g., vaccination) + no electronic medical record needs	0	Community vaccination clinic + paper registration of vaccination records + no cross-departmental collaboration	Innovation (CAS): No technical-task fitness (no EMR needs) Process: Remains in explore stage (no digital extension)
Organizational Culture	Proportion of young medical staff (<40 years old doctors) + acceptance of new technologies (training participation rate / system utilization rate)	1	Proportion of pediatric surgeons: 80% + training participation rate: 100% + system utilization rate >95% (e.g., full-process digital shift handover)	Moderators2 (Hospital digital transformation): Digital talent and governance Moderators2 (IDT): Incentive mechanisms (training integration)
	Balanced age structure of medical staff (50% above and below 40 years old) + training participation rate: 70% + system utilization rate: 70%	0.8	Ratio of senior pediatric physicians to young pediatric surgeons: 1:1 + partial departments use "parallel operation of old and new systems" for transition	Moderators2 (CAS): Moderate digital governance (partial adaptation) Institutional Theory: Normative pressure (gradual compliance)
	Mainly elderly medical staff (average age >55 years old) + system utilization rate <20% + refusal of training	0		Moderators2 (IDT): Low perceived ease of use CAS: Organizational rigidity (resistance to change)

After finalizing the assignment rules, the research team initiated the process of assigning values to the 43 original transcripts of in-depth interviews with pediatric departments from six hospitals. To ensure neutrality and accuracy, two independent research assistants with backgrounds in healthcare management research and data analysis were specifically selected to perform independent value assignments. Both assistants underwent systematic training on the "seven categories → five variables" framework and fuzzy value assignment criteria, which included analyses of specific cases (e.g., the leadership-driven digital informed consent system at Hospital 2, and the multi-level approval process for IT projects at Hospital 5).

A double-blind independent assignment method was employed: the two assistants independently allocated fuzzy values to each antecedent variable based on the interview transcripts without prior communication. For discrepancies that arose during the assignment process, consensus discussions were conducted by cross-referencing theoretical frameworks (such as Institutional Theory and Complex Adaptive Systems Theory) with the actual contexts of the hospitals (e.g., regional location, institutional nature). For questionable cases involving ambiguous leadership support in mixed-ownership hospitals, third-party domain experts were invited to participate in the validation, ensuring that the assignment results were consistent with theoretical logic while authentically reflecting the institutional characteristics in the interview transcripts. This rigorous assignment process effectively minimized individual subjective biases and provided a reliable guarantee for the scientific validity of subsequent fsQCA configurational analysis. The specific value assignments are detailed in Table 4.9.

Table 4.9 Assignment

ID	X1	X2	X3	X4	X5	Y
H1,1	1	1	0.4	0.4	0	1
H1,2	0.6	0.8	0.4	0.4	1	0.6
H1,3	0.8	1	0	0.2	0.4	0.8
H1,4	1	0.8	0	0.4	0	0.4
H1,5	0.8	1	0	0.6	0.4	0.8
H1,6	0.8	1	0.4	0.6	0	0.6
H1,7	0.6	0.8	0.4	0	0	0.6
H1,8	0.8	1	0.4	0	0.4	0.6
H1,9	0.8	1	0.4	0.4	0.4	0.8
H1,10	0.6	1	0.6	0.6	0.6	0.6
H2,1	1	0.4	0.8	0.8	0.4	1
H2,2	1	0.4	1	0.8	0.4	0.8
H2,3	1	0.4	1	1	0.4	0.8
H2,4	1	0	0.6	0.4	0.6	1
H2,5	1	0	1	1	1	0.8
H2,6	1	0.4	1	0.6	4	0.8
H2,7	1	0.4	1	1	0.4	1
H2,8	1	0.4	1	0.4	0.4	1
H2,9	1	0	1	0.4	0.6	0.8
H2,10	1	0.6	0.6	0.4	0.6	0.8

H2,11	0.8	0.4	1	0.2	0.2	0.4
H2,12	1	0.6	0.6	0.6	0.6	0.6
H3,1	0.4	0.2	0.8	0.4	0.2	0.4
H3,2	0.6	0	1	0.8	0.8	0.6
H3,3	0.6	0.2	0.6	0.4	0.6	0.4
H3,4	0.6	0.6	0.6	0.8	0.6	0.6
H3,5	0.4	0.6	0.6	0.6	0	0.4
H3,6	0.4	0	1	0.4	0.6	0.6
H3,7	0	0.6	1	0.6	1	0.6
H4,1	0.2	0	8	0.4	0.4	0.6
H4,2	0	0	1	0	0.4	0.6
H4,3	0	0.2	0.6	0.6	0.4	0.4
H4,4	0.2	0.2	0.2	0	0.4	0.4
H5,1	1	0	0	0.6	0.4	0.4
H5,2	1	0.6	0	0.4	0.4	0.6
H5,3	0.8	0.4	0.4	0.4	0.4	0.4
H5,4	1	0	0	0.6	0.6	0.6
H5,5	0.6	0	0.6	0.4	0	0.4
H5,6	0.4	0	0.4	0.6	0.2	0.4
H5,7	0.6	0.2	0.4	0.6	0.4	0.4
H6.1	0.6	0	0.4	0.4	1	0.4
H6,2	0.4	0.2	0	0.6	0.2	0.2
H6.3	0	0.2	0.2	0	0.6	0.2

4.4.5 Variables necessity analysis

Before testing the sufficiency of configurations, a necessity analysis of variables is first conducted to determine whether the outcome variable set is a subset of a conditional variable set. Consistency is a critical criterion for measuring necessary conditions, reflecting the degree to which case samples with a certain condition (attribute) exhibit the same outcome. Following Schneider et al.'s criteria (Schneider & Wagemann, 2012), this study sets the consistency threshold for necessary conditions at 0.9. The consistency levels of all antecedent variables are below 0.9, failing to constitute necessary conditions for the outcome variable. These antecedent conditions will be included in fsQCA for further exploration of configurations influencing the generation of high-outcome configurations, as shown in Table 4.10.

Table 4.10 Variables necessity analysis

Antecedent Variable	Consistency	Coverage
Leadership and Operations Factor	0.893	0.823
~Leadership and Operations Factor	0.362	0.721
Economic and Technological Factor	0.557	0.858
~Economic and Technological Factor	0.635	0.677
User Characteristics Factor	0.727	0.730
~User Characteristics Factor	0.399	0.675
Business Needs Factor	0.694	0.904
~Business Needs Factor	0.657	0.802
Organizational Culture Factor	0.590	0.894
~Organizational Culture Factor	0.708	0.765

4.4.6 Configuration testing

The sufficiency analysis in QCA is a crucial step to explore which conditions or condition combinations are sufficient to lead to specific outcomes. When conducting this analysis, it is necessary to set reasonable threshold values based on data characteristics to obtain more accurate and credible results (M. Zhang & Du, 2019). In this study, the case frequency threshold is set to 1, meaning all cases appearing at least once in the dataset are included in the analysis to retain as many cases as possible; the raw consistency threshold is set to the system default value of 0.8 to ensure a strong correlation between the analysed condition combinations and outcomes; PRI (Probabilistic Reliability Index) evaluates the robustness of solutions by considering the performance of condition combinations across different subsets or samples. Higher PRI values indicate that condition combinations maintain stable outcomes in different contexts, with a minimum requirement of 0.5 (Greckhamer et al., 2018). Considering the number of configurations and the heterogeneous roles of antecedent variables, a PRI consistency threshold of 0.85 is selected in this study. By comparing the intermediate solution and the parsimonious solution, the roles of each variable as core or peripheral conditions in configurations can be identified (Du & Jia, 2017). A total of 7 configuration paths were discovered. The consistency values of all configurations exceed 0.9, surpassing the minimum acceptable standard, with an overall consistency of 0.952. This indicates that these 7 configuration paths can be regarded as sufficient conditions for generating high-outcome configurations, explaining approximately 80.8% of the cases, as shown in Table 4.11.

Table 4.11 Configuration analysis

Antecedent Variable	Configuration 1	Configuration 2	Configuration 3	Configuration 4	Configuration 5	Configuration 6	Configuration 7
Leadership and Operations Factor	⊗	•	●	•	●	●	●
Economic and Technological Factor	⊗		⊗	⊗	•	•	•
User Characteristics Factor	●	●	●		⊗	⊗	
Business Needs Factor	⊗		●	●		⊗	⊗
Organizational Culture Factor		●		●	⊗		•
Raw Coverage	0.244	0.424	0.395	0.387	0.214	0.221	0.258
Unique Coverage	0.081	0.037	0.037	0.037	0.015	0.007	0.000
Consistency	0.943	0.975	0.991	0.991	0.935	0.968	1.000
Overall Coverage				0.808			
Overall Consistency				0.952			

Note: ●indicates the core condition is present;●indicates the peripheral condition is present;⊗ indicates the core condition is absent; ⊗ indicates the peripheral condition is absent.

User Characteristics-Driven Type (Configuration 1): With the user characteristics factor as the core condition and most other variables absent, this configuration is named "User Characteristics-Driven Type." It has a consistency of 0.943, covering approximately 24.4% of cases, with 8.1% of cases uniquely explained by this configuration. This path highlights the critical role of user needs in driving digital maturity. When parents have strong digital demands for pediatric medical services, hospitals will independently advance digital transformation due to user needs even if they lack leadership support or technological investment, demonstrating the independent driving effect of user needs.

User Characteristics-Organizational Culture Dual-Driven Type (Configuration 2): Featuring user characteristics and organizational culture as core conditions, with leadership and operations as a peripheral condition and others absent, this is named "User Characteristics-Organizational Culture Dual-Driven Type." With a consistency of 0.975, it covers 42.4% of cases, including 3.7% uniquely explained cases. This path demonstrates that when patients' digital service needs (e.g., online consultations, intelligent triage) and the hospital's organizational culture of accepting technological innovation and staffing support coexist as core conditions, digital maturity can be significantly enhanced even with weak other drivers. The synergy between young parents' high demand for medical convenience and the hospital's talent base and digital recognition strongly promotes the deepening of digital services like WeChat registration and online report queries, without relying on heavy technological investment or business process reconstruction.

Leadership, User Characteristics, and Business Needs Tripartite Synergy-Driven Type (Configuration 3): With leadership, user characteristics, and business needs as core conditions and economic and technological factors peripherally absent, this is named "Leadership, User Characteristics, and Business Needs Tripartite Synergy-Driven Type." With a consistency of 0.991, it covers 38.7% of cases, including 3.7% uniquely explained cases. This path indicates that the synergy among hospital management's strategic emphasis on digitalization, user digital service needs, and business process optimization needs can efficiently drive digital maturity even with low economic and technological investment. Driven by a digital special team led by the hospital director, user demands, and research project pressures are transformed into digital construction momentum, rapidly implementing digital projects.

Business Needs-Organizational Culture Dual-Driven Type (Configuration 4): With business needs and organizational culture as core conditions, leadership and operations as a peripheral condition, and economic and technological factors peripherally absent, this is named "Business Needs-Organizational Culture Dual-Driven Type." With a consistency of 0.935, it covers 21.4% of cases, including 1.5% uniquely explained cases. The collaboration between business needs and organizational culture forms a "needs traction-culture empowerment" dual-drive model. Driven by core business needs, hospitals upgrade digital equipment based on pain points in clinical diagnosis, nursing management, and other scenarios. When combined with a highly identity organizational culture, medical staff continuously participate in technical optimization due to high recognition of digital value, improving application proficiency and accuracy through operational experience accumulation and feedback iteration.

Leadership-Economic and Technological Dual-Driven Type: This category includes Configurations 5-7, where leadership and economic-technological factors are core conditions and other variables are mostly absent, named "Leadership-Economic and Technological Dual-Driven Type." These paths demonstrate that when hospital management makes digitalization a strategic priority, promotes it through institutional mandates, and provides adequate technological investment, digital maturity can be enhanced via resource input and institutional support—forming a "management strategic support-technological funding-driven" digital construction loop—even without clear business or user needs.

4.4.7 Robustness test

To ensure the robustness of the results, this study tests the configuration outcomes by adjusting the raw consistency threshold and PRI threshold. First, while keeping the case frequency and PRI threshold unchanged, the raw consistency threshold is increased to 0.85. Second, while keeping the case frequency and raw consistency threshold unchanged, the PRI consistency threshold is increased to 0.9. The new configuration paths, overall coverage, and consistency remain unchanged compared to the original configurations, confirming the robustness of the research results.

4.4.8 Results discussion

This study's findings are seems to corroborated and refined through a comprehensive comparison with established theoretical frameworks and empirical research across multiple domains, including innovation diffusion, institutional theory, complex adaptive systems (CAS), and healthcare digitalization studies. The multi-dimensional drivers of digital transformation identified herein， such as leadership commitment, economic-technological resources, user characteristics, business needs, and organizational culture—align closely with factors emphasized in prior studies. For instance, the emphasis on leadership-driven institutional compliance mirrors the coercive isomorphism mechanisms described by DiMaggio and Powell (1983), where external pressures from policies and regulations shape organizational behavior, while the adaptive thresholds and system resilience concepts resonate with Holland's (1995) CAS theory, which highlights how agents within systems learn and adapt through feedback loops. Additionally, the role of user characteristics (e.g., young parents' digital literacy) in accelerating technology adoption reinforces Rogers' (1962) Diffusion of Innovations Theory, particularly the dimensions of relative advantage, compatibility, and observability, which are critical for uptake in healthcare settings as noted by Greenhalgh et al. (2004) in their systematic review of innovation diffusion in service organizations. The configurational approach adopted in this study, using fsQCA to identify multiple pathways to high digital maturity, challenges traditional linear models and aligns with Ragin's (2008) emphasis on set-theoretic methods for understanding complex causality in social sciences. This contrasts with earlier works that often treated drivers in isolation, such as those focusing solely on technological investment (e.g., Melville et al., 2004) or policy mandates without considering interactive effects. Moreover, the focus on pediatric-specific contexts fills a gap in the literature, which has predominantly examined general hospitals or adult care settings, thereby extending theories like the Technology Acceptance Model (TAM) and Unified Theory of Acceptance and Use of Technology (UTAUT) by incorporating age-related demographics as key moderating variables, as suggested by Venkatesh et al. (2003). The study also resonates with Resource Dependency Theory (Pfeffer & Salancik, 1978) in highlighting how economic-technological resources influence organizational adaptation, and with structuration theory (Giddens, 1984) in explaining the interplay between agency and structure in digital transformation processes. Furthermore, the findings on the differences between hospital types (e.g., public vs. private) and their digital maturity pathways contribute to institutional theory by illustrating how normative and mimetic isomorphism operate in healthcare environments, as initially framed by Scott (1995). By integrating these diverse theoretical perspectives, this research not only validates existing constructs but also offers a more nuanced, context-sensitive framework that accounts for the unique complexities of pediatric healthcare digitalization, providing a foundation for future comparative studies across healthcare subsystems and regions.

1. The Primacy of User Characteristics in Pediatric Settings and the “Caregiver-Centric” Diffusion Model

The analysis underscores that user characteristics (X3) appear as a core or peripheral condition in five of the seven high-maturity pathways (Configurations 1, 2, 3, 5, 6), highlighting its unparalleled importance. This finding resonates deeply with the interview data and refines the application of Innovation Diffusion Theory (IDT) in pediatric contexts.

Unlike adult healthcare, where the patient is often the primary user, pediatric digital transformation is fundamentally caregiver-mediated. The high digital maturity observed in specialized women's and children's hospitals (H2) and certain private clinics (H4) was directly fueled by a patient base composed of young, digitally-native parents. As interviewees noted, this demographic exhibits high compatibility (Rogers, 1962) with digital tools, reducing perceived complexity. For instance, H2 achieved a 95% patient acceptance rate for mobile registration as early as 2010, and H1's "one-code" medical care significantly improved satisfaction by streamlining processes for young parents. Their high digital literacy lowered the adoption barrier, creating a natural pull force for digital services like online appointment booking, report queries, and vaccination reminders.

Furthermore, the fsQCA shows that strong user characteristics can even compensate for the absence of other strong drivers. Configuration 1 demonstrates that high maturity can be achieved primarily through robust user demand, even with relatively weaker institutional leadership or technological investment. This suggests that in pediatric care, a highly digitally-engaged caregiver population can create a bottom-up imperative for transformation, forcing hospitals to adapt and invest in digital interfaces to meet patient expectations, a dynamic less commonly observed in geriatric or general patient populations.

2. Organizational Culture as the Catalytic Glue: Bridging Strategy and Execution

The results position organizational culture (X5) not merely as a supporting factor but as a critical catalyst that amplifies the effect of other conditions. It appears as a core element in Configurations 2 and 4.

The case studies provide vivid examples of this catalytic role. Hospital 1's pediatric surgery department, staffed primarily by younger, tech-savvy surgeons, served as internal "early adopters." They readily embraced AI-assisted surgical planning and digital postoperative follow-up systems, demonstrating the technology's relative advantage and observability to both the administration and hesitant colleagues. This created a positive feedback loop that accelerated wider adoption. Conversely, Hospital 6 and the pediatric internal medicine departments in larger hospitals (H5) faced significant inertia. Despite allocated funds for smart devices, resistance from senior staff accustomed to paper-based workflows led to low utilization rates (e.g., below 40% for smart ward systems at H6). This contrast highlights that a resistant culture can dissipate the energy from strong leadership mandates and financial investment, while an adaptive culture can leverage even moderate resources to achieve significant outcomes by ensuring smooth implementation and sustained usage.

3. The Dual Edges of Leadership and Resource Investment: The Imperative of Strategic Alignment

While leadership-operational synergy (X1) and regional-technological resources (X2) are powerful drivers (evident as core conditions in Configurations 3, 5, 6, 7), the findings crucially indicate that they are necessary but not sufficient for sustainable, high-value digital maturity. Their effectiveness is contingent upon alignment with core user needs and business objectives.

Hospital 5's experience is a cautionary tale. It pursued high-level EMR certification (Level 6) driven by leadership and significant investment (¥80 million+ annually). However, a portion of this investment was directed towards systems designed more for meeting national rating standards than addressing specific pediatric clinical workflows or caregiver usability. This resulted in "digital waste" – advanced functionalities that were underutilized because they did not solve acute pain points. In contrast, Hospital 2's leadership success was rooted in its ability to strategically align digital investments with its core business needs: high-quality, structured data for its massive research programs (e.g., maternal and child cohorts). This alignment ensured that the digital transformation directly served a critical organizational mission, guaranteeing funding, clinician buy-in (as it eased their research workload), and ultimately, high maturity. This aligns with Institutional Theory, showing that leadership is most effective when it strategically navigates coercive pressures (e.g., ratings) by linking them to the organization's specific normative and cognitive-cultural imperatives (research excellence in H2's case).

4. Configurational Pathways and Hospital Typology: Towards Differentiated Digital Strategies

The seven pathways effectively create a typology of digital transformation strategies suited for different types of pediatric care providers, moving beyond one-size-fits-all recommendations.

For Large Public Specialty Hospitals (e.g., H2): Configurations 3 and 7 are most relevant. Their path is characterized by tripartite synergy: strong leadership orchestrating resources to simultaneously meet policy mandates (coercive isomorphism), advance research business needs, and serve a digitally-demanding user base. Their strategy should focus on integration and leveraging scale for research-driven innovation.

For Resource-Constrained or Smaller Public Hospitals (e.g., H6): Configuration 4 offers a viable path. Lacking the massive resources of H2, they can achieve maturity by fiercely focusing on a few, critical business needs (e.g., streamlining outpatient efficiency) and cultivating a supportive internal culture that embraces incremental, high-impact digital changes. Their strategy is one of focused agility.

For Private and International Hospitals (e.g., H3, H4): Configurations 1, 2, and 5 are illustrative. Their strategy is inherently user- and market-driven. For H3, the pathway involved overcoming institutional misfit (e.g., medical insurance system integration) to serve its niche user base. For H4 (clinics), maturity was driven by celebrity doctors (KOLs) acting as innovation champions, directly responding to and shaping high user expectations for personalized, convenient care. Their strategy revolves around differentiation through superior user experience and service personalization.

Chapter 5: Conclusion

5.1 The main conclusions

This study systematically answers the research questions by integrating multi-source interview data, three-level coding results, and fuzzy-set qualitative comparative analysis (fsQCA), establishing both theoretical connections and empirical validation. The methodological design, which combines qualitative coding with quantitative comparative analysis, allows for in-depth analysis of the complex dynamics underlying digitalization in pediatric hospitals.

Research Question 1: What are the dimensions, process, and outcomes of digital transformation in pediatric hospitals?

Dimensions: This study identifies five core dimensions that constitute the foundational framework for pediatric digital transformation:

Leadership and Operational Synergy: The strategic determination of hospital management to drive digital transformation, decision-making efficiency, and the ability to integrate digital goals into organizational operations and performance assessments.

Regional Economy and Technological Resources: The level of financial support from the hospital's region, the reserve of digital talent, and the hospital's own investment in hardware infrastructure, software systems, and in-house R&D teams.

User Characteristics: The digital literacy of core users (primarily young parents), their acceptance and usage habits of online services. This is a distinctive feature differentiating pediatric care from other medica departments.

Business Needs: The urgent demand for digital tools and structured data from clinical diagnosis and treatment (e.g., multi-disciplinary consultations), scientific research (e.g., large-scale cohort studies), and hospital management (e.g., lean operations).

Organizational Culture: The willingness of medical staff, particularly young key members, to learn and accept new technologies, along with the atmosphere for collaborative innovation across departments.

Process: The transformation is not an overnight event but a dynamic, multi-stage cyclic process of "implementation-interaction-coordination-feedback-iteration." It begins with the strategic cognition of leadership, translates requirements into specific projects through interaction with clinical and management departments, coordinates resources and overcomes resistance during implementation, and undergoes continuous iterative optimization based on user feedback and effectiveness evaluation.

Outcomes: The final results of transformation are reflected in the enhancement of digital maturity, measured by standards including:

Depth of Technology Application: Achieving high levels of electronic medical record system application (e.g., Level 6 or 7).

User Experience and Satisfaction: Patients (and their families) gain more convenient, precise, and personalized services, leading to increased satisfaction.

Operational and Diagnostic Efficiency: Internal hospital processes are optimized, resource allocation becomes more rational, and medical staff's work efficiency improves.

Data-Driven Capability: Providing powerful data support for clinical research and high-quality management decision-making.

Research Question 2: How do different types and levels of pediatric hospitals differ in their digital transformation processes and outcomes?

Through multi-case comparison and fsQCA analysis, this study reveals significantly divergent transformation paths among different hospitals:

Large Public Specialty Hospitals (e.g., H2): Their path is characterized by a tripartite strong synergy of "leadership-resources-business needs." Leveraging strong administrative resources (e.g., policy assessment pressure, fiscal allocations) and scale advantages, they drive large-scale, systematic digital transformation with the dual goals of achieving high-level evaluations (e.g., EMR ratings) and supporting national research projects. The outcome is reflected in high-level, comprehensive digital maturity.

Resource-Limited Small and Medium-Sized Public Hospitals (e.g., H6): Their typical path is focusing on core business needs and relying on organizational culture for breakthrough. Due to limited resources, they cannot deploy transformations comprehensively. Instead, they select specific pain points (e.g., optimizing outpatient workflows) for precise digital transformation, heavily relying on an internally formed efficient, agile, and change-embracing team culture to drive implementation and achieve practical results.

High-End Private/International Hospitals (e.g., H3, H4): Their path is distinctly user and market-driven. The core goal of transformation is to meet the demand for personalized, high-quality services from their specific clientele (high-income, highly educated parents). They focus more on extreme optimization of user experience (e.g., personalized follow-up, privacy protection, multilingual support). Digital transformation is a key means for them to build a premium service brand and market competitiveness.

Research Question 3: What are the relationships among the antecedent factors, process, and outcome of digital transformation in pediatric hospitals?

These three elements do not share a simple linear causal relationship but form a dynamic coupling and an organic whole of "antecedent configuration → process synergy → outcome realization".

Antecedent Configuration is the Starting Point and Foundation: Different hospitals possess different combinations of antecedent conditions (i.e., "configurations"), which determine the initial driving force and constraint boundaries of their transformation. For example, a hospital with young parents as users and abundant resources has a completely different starting point from one with an aging user base and scarce resources.

Process Synergy is the Conversion Hub: The antecedent configuration must be translated into outcomes through the implementation process. The core of this process is synergy and adaptation. For instance, strong leadership (antecedent) requires the establishment of cross-departmental agile teams (process) to coordinate clinical and IT departments to land strategic intentions. A good user base (antecedent) requires continuous feedback collection and system iteration (process) to genuinely enhance satisfaction.

Outcome is the Final Emergent Manifestation: High digital maturity is the emergent result of antecedent conditions synergized through efficient processes. The multiple conjunctural causality and equifinality (i.e., different antecedent combinations can achieve the same high maturity through different process paths) revealed by fsQCA analysis are the most direct evidence of this complex relationship. It shows that there is no single best path; the key to success lies in finding the process mode that best matches one's own antecedent configuration. see Figure 5.1.

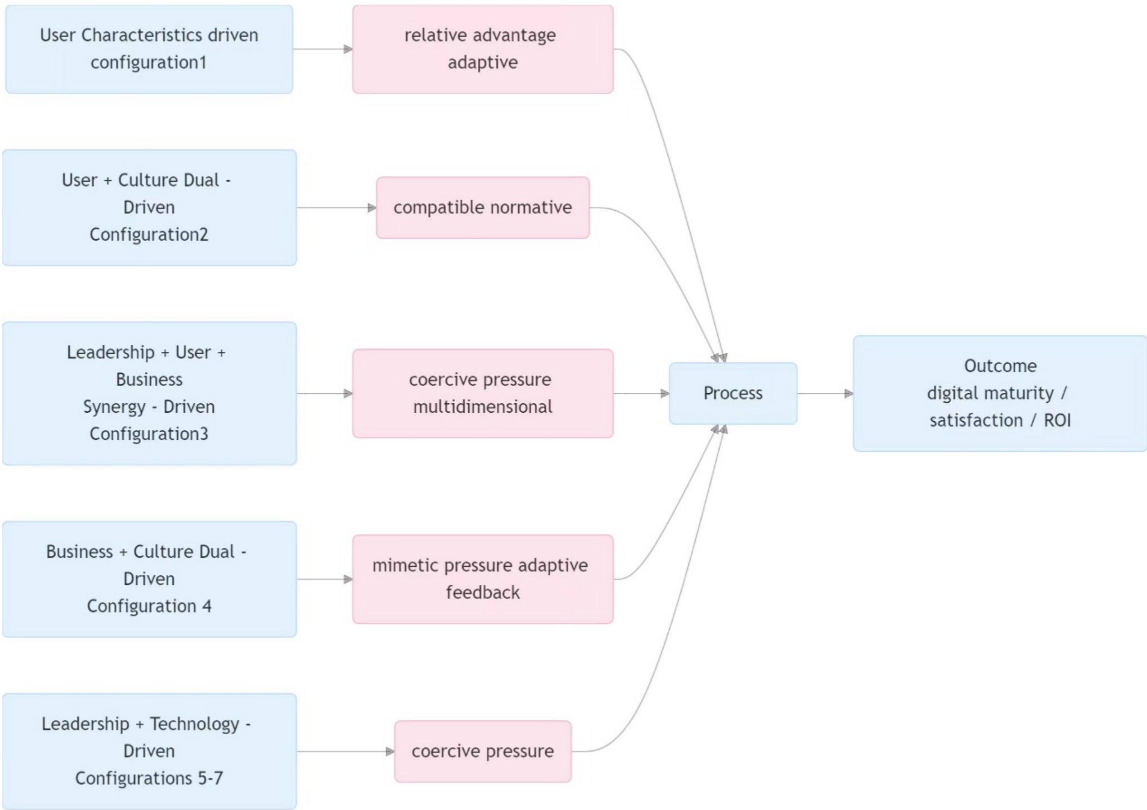

Figure 5.1 Model combining theory and empirical evidence

5.2 Contributions

This study makes significant contributions to both theoretical development and practical guidance in the field of pediatric hospital digitalization, as outlined below:

5.2.1 Theoretical contributions

First, this research advances the theoretical discourse on digital transformation by moving beyond siloed perspectives and developing an integrated framework that combines Innovation Diffusion Theory, Institutional Theory, and Complex Adaptive Systems (CAS) Theory. While prior studies have often applied these theories in isolation, this work demonstrates their complementary nature in explaining the complexities of digital adoption in healthcare. The resulting framework offers a more nuanced understanding of how institutional pressures, innovation attributes, and adaptive organizational processes interact to shape digital maturity.

Second, the study introduces the concept of *configurational pathways*to the domain of healthcare digitalization. By employing fsQCA, we identify multiple, distinct combinations of conditions that lead to high digital maturity, thereby challenging linear, one-size-fits-all models of transformation. This approach highlights the principle of equifinality and provides a theoretical basis for understanding why different types of hospitals—despite varying resources and constraints—can achieve similar levels of digital success through different strategic routes.

Third, the research extends the application of CAS theory by identifying and conceptualizing the *adaptive threshold*—a critical point where technological investments and organizational readiness must align to avoid inefficiencies and resistance. This concept adds depth to existing CAS applications in healthcare, offering a dynamic model that accounts for the necessary balance between change and stability during digital transformation.

5.2.2 Practical contributions

From a practical standpoint, the findings offer actionable insights for hospital administrators, policymakers, and IT strategists. The identification of specific configurational pathways provides a diagnostic tool for hospitals to assess their own strengths and weaknesses. For instance, a resource-constrained hospital might focus on leveraging strong user demand and a supportive organizational culture, while a larger institution might prioritize leadership-driven initiatives coupled with strategic investments.

Moreover, the study highlights the importance of context-specific strategies. Pediatric hospitals, with their unique patient demographics and operational challenges, require tailored approaches to digital transformation. The emphasis on young, digitally literate parents as key drivers of change, for example, suggests that patient engagement and personalized digital services should be central to transformation efforts in these settings.

Finally, the research offers guidance for policymakers aiming to promote regional healthcare digitalization. By understanding the synergistic effects of economic support, regulatory pressures, and institutional culture, policymakers can design more effective incentives and support systems to encourage digital maturity across diverse healthcare organizations.

In summary, this study not only enriches the theoretical landscape of digital transformation research but also provides a practical roadmap for pediatric hospitals navigating their digital journey, ultimately contributing to more efficient, responsive, and high-quality pediatric care.

5.3 Research limitations and outlook

5.3.1 Research limitations

This study, while providing meaningful insights, acknowledges several inherent limitations that warrant consideration when interpreting its findings.

First, the sample selection, though strategically designed to capture diverse hospital types, possesses inherent geographical and structural constraints. All six hospitals are located within the Pearl River Delta region, a highly developed economic zone in China. While this provided a controlled context for comparing institutional differences, it limits the generalizability of the findings to pediatric hospitals in less developed regions or countries with vastly different healthcare systems. The digital transformation challenges and resource environments in underdeveloped or rural areas are likely to be fundamentally different, and our model may not fully capture those dynamics.

Second, the methodological approach, combining qualitative interviews and fsQCA, prioritizes depth of understanding over statistical generalizability. The sample size of six hospitals, while sufficient for a robust qualitative comparative analysis, means the identified configuration paths represent potent combinations found within this specific dataset rather than statistically representative patterns of the entire population of pediatric hospitals. The findings are exploratory and indicative, serving as a framework for hypothesis testing in future large-N studies.

Third, the study faces inherent constraints related to data access and measurement. The assessment of "digital maturity" relied on a combination of official ratings (e.g., EMRAM levels), interview data, and internal documents. While we sought to triangulate these sources, the absence of a universally standardized, objective, and granular metric for digital maturity means our dependent variable is ultimately a constructed measure. Furthermore, some quantitative data, such as precise financial investment figures in digital infrastructure or exact ROI calculations, were often treated as sensitive information by the hospitals and were not fully disclosable, potentially leading to an underrepresentation of the economic dimension in our configurations.

Finally, the research design captures a snapshot in time. Digital transformation is not a static outcome but a dynamic, evolving process. The configurations identified represent pathways to a certain level of maturity at this point in time. The model does not explicitly address the temporal evolution of these pathways—how a hospital might transition from one configuration to another as strategies, technologies, and external pressures change over time. A longitudinal study would be required to understand these dynamic processes better.

5.3.2 Future research outlook

Based on these limitations, several promising avenues for future research emerge.

1. Expanded Geographical and Systemic Scope: Future studies should test and refine the proposed configurational model across a broader geographical spectrum, including pediatric hospitals in mid-western China and other developing countries. Research could also compare publicly funded versus privately funded healthcare systems in different national contexts to understand how overarching healthcare policies and funding models interact with the identified antecedent conditions.

2. Longitudinal and Process-Oriented Studies: To move beyond static snapshots, researchers should employ longitudinal case studies or panel data analysis. This would allow for the examination of how digital transformation pathways evolve, how hospitals navigate from low to high maturity, and how they adapt their strategies in response to technological disruptions (e.g., the rapid adoption of generative AI) and shifting policy landscapes.

3. Development and Validation of a Digital Maturity Metric: A significant contribution would be the development of a validated, multi-dimensional scale for measuring digital maturity in hospitals, particularly for pediatric care. This scale could integrate technical, organizational, and human factors and be applied quantitatively to larger samples, enabling more robust statistical testing of the relationships proposed in this study.

4. Micro-foundations of Macro-Configurations: While this study focused on organizational-level factors, future research could drill down into the individual and team levels. Investigating the micro-foundations—such as the digital literacy of medical staff, leadership styles of department heads, or the interplay between clinical workflows and technology interfaces—would provide a more granular understanding of how the macro-configurations actually operate and succeed in practice.

5. Impact on Patient Outcomes: Ultimately, the value of digital transformation is measured by its impact on patient care. A crucial next step is to link the different configurational pathways not just to maturity scores but to hard outcomes such as patient safety indicators, treatment efficacy, waiting times, and long-term patient satisfaction. This would solidify the practical significance of digital transformation research for healthcare delivery.

In conclusion, this study offers a foundational framework for understanding the complex, multi-faceted nature of digital transformation in pediatric hospitals. By acknowledging its limitations and embracing the outlined future directions, scholars can build upon this work to advance both theory and practice, ultimately contributing to the creation of more agile, efficient, and patient-centered pediatric healthcare systems for the future.

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Annex A: Interview Consent Form

Research Title: Differences in Pediatric Digital Transformation Maturity and Influencing Factors

Researcher: Wang Xutong(PhD Candidate)

Affiliation: ISCTE

Contact: Email 18818885666@126.com

Part 1: Research background and purpose

This study aims to explore differences in pediatric digital transformation maturity across hospitals and analyze the impact of technology, management, and policy on this process. Your expertise will provide critical empirical insights into:

1. Current applications of pediatric digital systems (e.g., electronic medical records, AI-assisted diagnostics).

2. Key barriers to digital transformation (e.g., technical adaptability, data interoperability, clinician acceptance).

3. The role of policies and resource allocation in shaping outcomes.

Part 2: Participation details

1. Interview Format:

in-person (hospital meeting room), approximately 60 minutes.

Choose between audio recording or written notes (check preferences below).

2. Key Topics (tailored to your role):

IT Staff: System architecture, data governance, operational challenges.

Clinicians: User experience with digital tools, impact on clinical efficiency.

Hospital Leaders: Strategic planning, resource allocation, policy implementation challenges.

Part 3: Data use and confidentiality

1. Data Collection: Audio/notes will be used solely for research analysis; raw files will not be shared.

2. Data Processing: All information will be anonymized (e.g., "IT Engineer from Hospital A" instead of real names); Sensitive remarks (e.g., critiques of policies) will be generalized to remove institutional/geographic identifiers.

3. Data Storage and Disposal: Audio files will be stored on university encrypted servers and permanently deleted after December 31, 2026; Identifiable information in transcripts will be redacted.

4. Data Usage: PhD dissertation writing; Academic publications (e.g., Chinese Journal of Hospital Administration); Policy recommendations (aggregated results only, no individual data).

Part 4: Participant rights

1. Voluntary Participation:

You may decline to participate or withdraw at any time without penalty.

2. Right to Information: Request access to anonymized interview summaries; Receive a copy of the published dissertation upon completion.

3. Privacy Protection: Report data misuse concerns to the ethics committee (contact details below).

Part 5: Consent statement

I have read and understood the above terms and voluntarily agree to participate.

Consent to Audio Recording: □ Yes. □ No.

Consent to Written Notes: □ Yes. □ No.

Signature: ___________________________

Date: ___________________________

Printed Name: ______________________

Position/Department: ________________

Attachments

Researcher Confidentiality Pledge:

"I pledge not to disclose raw interview data to third parties without written consent. All published content will be anonymized."

Researcher Signature:

Contact Information

Research inquiries: Wang Xutong (Email: 18818885666@126.com)

Notes

This form will be retained by both researcher and participant;

Electronic signatures are legally binding.