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Constructing a Dual-Layer Pathway for Data Governance of Children in Difficult Circumstances

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Abstract: Addressing the three governance challenges currently facing child protection—information silos, policy attenuation, and service mismatches—this study integrates welfare governance theory with a data governance framework, combining perspectives on holistic governance and collaborative governance to construct a two-tier governance architecture comprising "provincial smart hubs" and "municipal service response hubs." The study innovatively proposes the following perspectives: First, based on institutional anti-fragmentation mechanisms, it addresses the attenuation of policy transmission across hierarchical levels through the semantic digitization of policies (converting policy texts into computable metadata). Second, it constructs a legally compliant data ownership framework, establishing the principle of graded authorization—separating ownership, management rights, and usage rights—in accordance with the "Personal Information Protection Law of the People's Republic of China" and the "Minors Protection Law of the People's Republic of China". Third, a three-dimensional trust-building model (transparency, contractualization, and normalization) is established to facilitate value co-creation between government and society. Theoretical analysis indicates that provincial-level smart hubs, through privacy-preserving computing technologies (such as federated learning), enable cross-departmental collaborative model training and can effectively integrate risk insights without exchanging raw data. Municipal-level service response hubs rely on verification mechanisms to ensure the integrity of source data, forming a closed-loop of collaborative governance involving "institutions—technology—actors." This framework can effectively drive the transformation of child protection toward data-driven decision-making, resilient service delivery, and a paradigm of co-creation between government and civil society.

Keywords: Protection of Children in Difficult Circumstances; Data Governance; Digital Divide Compensation; Three-Dimensional Trust Generation Model

1. Introduction

1.1 Problem Analysis and Governance Challenges

The child assistance and welfare system is an important part of the national social security system. Due to the multiple vulnerabilities of children such as economic poverty and lack of supervision, children are the key protection group of relevant policies. Currently, in the context of the global digital transformation wave, data-driven has become an inevitable path to improve the effectiveness of child protection and welfare governance [1]. However, currently child protection is mainly faced with three structural contradictions in terms of data drive, application and governance: First, the phenomenon of information islanding. That is, it is difficult to share and use information between different relevant departments. Including civil affairs, education, health and other departments, due to different data standards, unclear ownership, and blockage, it is "difficult to coordinate with data" [2]; secondly, there is the problem of vertical attenuation of policies. In the current five-level administrative system of the country, policy semantics are dissipated and implementation is distorted in the hierarchical transmission [3], leading to the dissolution or alienation of policy intentions at the grassroots level. Similar problems are particularly prominent in complex scenarios such as remote areas, rural areas, and grassroots intergenerational guardianship; third, there is a dynamic mismatch of service needs. Compared with the current situation of rapid changes and

complex diversification of children's needs, it is difficult to respond to static supply in a timely manner, which further aggravates the imbalance between service supply. It is particularly worth noting that the digital divide prevalent in remote areas such as rural areas (shown as triple gaps in low network coverage, low ownership of smart terminals, and insufficient digital literacy among key actors) [4] not only further aggravates the above three contradictions, but also constitutes a core bottleneck in the equalization of urban and rural child welfare services.

1.2 Literature Review and Theoretical Gaps

Existing relevant research mainly includes the following aspects: research on policy integration systematically explains the necessity of transforming child welfare from a gap-filled to an inclusive one [5]; research on government sharing mechanisms focuses on the construction of cross-departmental trust [2]; research on social participation paradigms further reveals the advantages of social organizations in the provision of professional services [6]. However, existing research still has shortcomings in the following aspects. First, there is a lack of a systematic governance framework to build "hierarchical integration-department collaboration-rural adaptation"; secondly, the legal compliance design and risk avoidance of data ownership configuration in the context of "Personal Information Protection" [7] and "Minor Protection" [8] are ignored; then, in the construction There are shortcomings in building a coupling mechanism that effectively promotes the generation of trust among multiple subjects (-society-family) [9]; finally, there is a lack of targeted and systematic compensation mechanisms and response plans for the fundamental constraint of the rural digital divide and its constraints on data governance effectiveness.

1.3 Research Approach and Theoretical Contributions

To bridge the aforementioned theoretical gap, this study proposes an integrative "institution-technology-actor" collaborative governance model: Framework Design: A two-tier governance structure comprising "provincial smart hubs" and "municipal service response hubs" is established, drawing on the theory of scale reorganization [10]. The provincial hub focuses on institutional rule translation and cross-domain technological integration, while the municipal service response hub concentrates on activating grassroots actor networks, implementing rural scenario-based applications, and addressing key tasks in digital divide compensation. Core innovative mechanisms include: First, Institutional layer: Policy digital transition mechanism and a legally compliant structured data ownership framework; Second, Technological layer: Privacy-preserving computation (federated learning + differential privacy) empowering secure cross-departmental collaboration; Finally, Actor layer: A three-dimensional trust generation model (data transparency, responsibility contractualization, and interaction normalization). By integrating multiple theoretical perspectives, this study constructs an explanatory three-dimensional collaborative governance framework of "institution-technology-actor" (see Figure 1), providing a systematic solution for data governance of children in difficult circumstances and promoting the paradigm shift in child welfare governance towards data-driven, dynamic response, and multi-stakeholder co-governance. Figure 1 illustrates the dual-layer structure of the Provincial Intelligent Hub and the Municipal Service Response Hub, as well as their interactive relationships with the three dimensions of institution, technology, and actor.

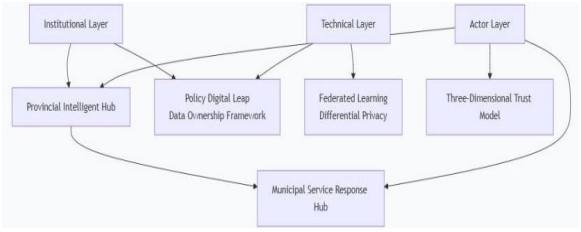


Figure 1. Three-Dimensional Collaborative Governance Framework

2. Theoretical Framework: Construction Logic of the Three-Dimensional Integration Model

Grounded in the public value orientation of welfare governance [11] and the technical rationality principles of data governance [12], this study integrates the hierarchical reconstruction logic of holistic governance with the networked action logic of collaborative governance [9]. It constructs a three-dimensional integration model of

"institution-technology-actor," providing the theoretical foundation and design logic for the dual-layer governance pathway of the "Provincial Intelligent Hub-Municipal Service Response Hub," and systematically addressing the structural contradictions in data governance for children in difficult circumstances.

2.1 Institutional Layer: Rule Reconstruction for Institutional Anti-Fragmentation

Drawing on the core ideas of Ostrom's theory of property rights delineation [13], we can establish an enforceable system of rules by clearly delineating data ownership, management rights, usage rights, and their boundaries (gradient authorization). This approach addresses the transaction costs and barriers to collaboration arising from ambiguous rights allocation across departments, thereby proactively resolving the structural fragmentation caused by bureaucratic divisions. This mechanism comprises two core aspects:

First, a digital transformation mechanism for policy enforceability. This mechanism uses technical means to convert abstract, text-based policy provisions into a metadata framework that machines can parse. This includes establishing a cross-departmental, consensus-based data dictionary [14] (for example, a standardized definition of "lack of guardianship" as a continuous period of ≥72 hours without guardian care) to ensure uniform data standards. In addition to static demographic data, time-series variables reflecting the specific vulnerabilities of remote and rural areas (such as seasonal poverty and the proportion of intergenerational care) are introduced to establish policy response thresholds, thereby making policies more context-adaptive.

Second, a structured framework for data ownership. In accordance with Article 13 (Informed Consent) of the "Personal Information Protection Law" and Article 72 (Best Interests Principle) of the "Minors' Protection Law", establish a graduated authorization principle that separates ownership, management rights, and usage rights (see Table 1).

Table 1. Legally Compliant Graduated Authorization Framework for Data Ownership

Ownership Level	Rights Holder	Scope of Authority	Technical Implementation Guarantee
Ownership	Child/Guardian	Informed consent, right to withdraw	Electronic signature evidence storage
Management	Provincial Hub	Security governance / standard setting / cross-domain coordination	Blockchain audit tracing
Usage	Municipal Hub	Data lifecycle management / quality verification	Tamper-proof operation logs
Usage	Government Departments	Risk screening (desensitized identifiers)	Federated learning + differential privacy
Usage	Social Organizations	Service matching (aggregated statistics)	Trusted Execution Environment (TEE)

Table 1 systematically presents a structured framework for data ownership in legal compliance. This framework resolves disputes over data ownership between departments, establishes a legal foundation for secure and compliant data sharing, and thereby promotes integration at the institutional level.

2.2 Technological Layer: Collaborative Pathway Empowered by Privacy-Preserving Computation

To address the inherent tension between data sharing and privacy protection, a "technology-enabled dual-track collaborative approach" has been designed. This approach strikes a balance between the needs for data utilization and privacy protection:

(1)Technical Implementation of Vertical Interconnectivity

By formulating and implementing standardized interface chain protocols (such as using the JSON-LD format to define specifications for cross-tier data transmission, which facilitates semantic interoperability) [15] and designing lightweight data collection protocols, we ensure that policy directives and necessary data can be transmitted between different tiers without loss and with high efficiency.

(2)Privacy Protection through Horizontal Integration

Federated learning serves as the core engine for horizontal integration [16], enabling cross-departmental collaborative model training (each department trains models locally using raw data → uploads only encrypted model gradients or parameter updates → the provincial level securely aggregates these updates → generates updated global model parameters →

distributes the updated parameters to all departments → each department updates its local model), supplemented by differential privacy techniques [17] to enhance data security. Through the integrated use of the above technologies, it is possible—while effectively safeguarding the privacy and security of individuals' raw data—to achieve both collaborative data utilization and joint analysis across departments, as well as to effectively increase the volume and scientific rigor of data used for model training.

2.3 Actor Layer: Three-Dimensional Trust Generation Model

In response to the practical challenge of effectively achieving collaborative participation among multiple stakeholders (government departments, social organizations, communities, families, etc.) in current child protection practice for children in difficult circumstances, this study attempts to construct a "three-dimensional trust generation model." This model posits that trust building depends on the coupling effect of institutional norms and technological tools, and its specific design is based on the following three dimensions.

First," Data Transparency." Open and transparent data management rules and usage logs are established so that all participating stakeholders can clearly understand the entire process of data collection, use, and sharing; all traces are clearly traceable and auditable, thereby enhancing their trust in the entire governance process.

Second, "Contractualization of Responsibilities." The rights, obligations, and responsibility boundaries of each participating stakeholder are clearly defined through institutional arrangements, and contractual relationships are consolidated through technological means such as electronic signatures. Relevant records are retained to reduce uncertainty in cooperation.

Third, "Regularized Interaction." Mechanisms are established to ensure routine communication and collaboration among stakeholders, such as online collaboration platforms and regular joint meetings. At the same time, these mechanisms should be adapted to the specific circumstances of children in difficult circumstances; for example, operation instruction videos can be provided in local dialects, and proxy notification channels can be established to relay information to guardians in special situations such as skip-generation guardianship.

These three dimensions mutually reinforce and strengthen one another: data transparency serves as the foundation and bedrock of trust; contractual accountability serves as the safeguard and backbone of trust; and regular interaction serves as the means of sustaining trust. Together, they form a progressive theoretical loop (see Figure 2).

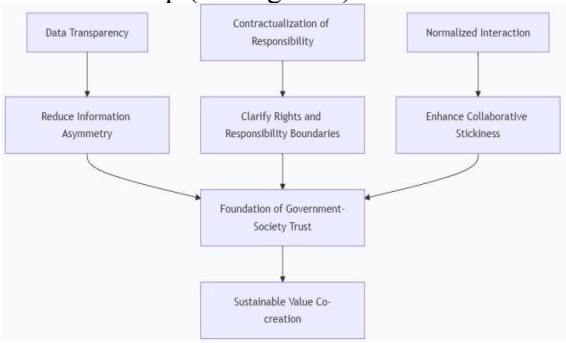


Figure 2. Operational Pathway of the Three-Dimensional Trust Generation Model

3. Operational Mechanism Design of the Dual-Layer Governance Framework

Based on a three-dimensional integrated model of "institutions—technology—actors," this study constructs a two-tier architecture comprising "provincial smart hubs" and "municipal service response hubs." At its core is the goal of achieving institutional de-fragmentation through differentiated functional configurations and dynamic coordination mechanisms. This design adheres to three key principles: "vertical institutional integration, horizontal technological integration, and agile grassroots response."

3.1 Provincial Intelligent Hub: Scale Reconstruction of Institution and Technology

Within this framework, provincial-level platforms serve as "triple converters" for macro-level governance and play a central role in empowering the system.

(1) Policy-Data Converter

Deconstruct the child welfare policies issued by the national government and transform them into a concrete, calculable, and quantifiable system of indicators. At the same time, this process identifies and corrects any potential attenuation in policy transmission across administrative levels. By using metadata to constrain the discretionary authority of grassroots-level agencies—for example, defining that "lack of guardianship" must

include three types of supporting evidence: GPS tracking, school-parent sign-ins, and neighborhood verification [14]—we ensure that the policy's intent is accurately reflected at the data level.

(2) Data-Knowledge Converter

Leveraging a federated learning technology engine, the system effectively integrates the encrypted gradient parameters generated by locally trained models across various departments—such as updates to the health risk model from the health department, the academic risk model from the education department, and the guardianship risk model from the social welfare department—to ultimately aggregate and update these data at the provincial platform level, thereby constructing a comprehensive risk prediction model. The key metrics output by the global risk prediction model—such as risk scores and the contribution of key features—are cross-referenced and analyzed in conjunction with entity relationships (e.g., children, guardians, schools, communities) extracted from the integrated data, thereby constructing and dynamically updating a global risk knowledge graph [18]. Consequently, this approach not only provides a visual representation of the risk distribution of potential issues, associated factors, and pathways for early prevention and intervention but also enhances the model's data insights, analytical capabilities, and decision-support capabilities.

(3) Demand-Resource Converter

Based on the above global risk knowledge map, combined with the desensitization demand tags (type, urgency, region, etc.) uploaded on the municipal platform, and fully considering the provincial level welfare resource supply level, including funds, projects, institutional service capabilities, etc., a comprehensive cross-regional resource allocation strategy and priority rules are formulated [19]. Provide resource matching algorithm models and scheduling guidance for municipal platforms, promote the precise connection of resources and demand, and achieve resource supply that pays equal attention to precision, efficiency, elasticity and flexibility.

3.2 Municipal Service Response Hub: Scenario-Based Anchor for Actor Networks

The municipal service response hub is the core anchor that brings together relevant participants. Its responsibilities include providing unified data entrances, standardized interfaces, transparent responsibility chains, and convenient collaboration ports. The municipal service response hub can effectively coordinate costs, clarify action boundaries, and stimulate the vitality of multiple parties. Its ultimate goal is to ensure that the institutional intentions, decision-making opinions, and technical capabilities at the provincial level can be accurately implemented in complex and ever-changing grassroots scenarios.

(1) Source Quality Assurance Mechanism (Institution-Technology Coupling)

A "entry-review-feedback" three-tier verification mechanism is constructed to ensure source data quality [19], designed at the data collection end. Entry level: Metadata constraints (e.g., dialect voice-to-text input) [20]; Review level: Logical conflict detection (e.g., spatial topology verification, geographical contradictions between school location and workplace); Feedback level: Data quality traceability and accountability chain (e.g., traceable and non-repudiable technical means such as operation log records and electronic signature evidence storage for responsible persons). Innovations are combined with rural realities to ensure data accuracy and reliability.

(2) Scenario-Based Response Engine (Technology-Actor Coupling)

The "interaction normalization" mechanism at the actor layer promotes collaborative responses by government and social forces to changes in children's status [21]. This mechanism is designed with flexibility to promptly identify and effectively handle the dynamic changes in the identity of children in difficult circumstances in remote rural areas. It incorporates a built-in digital divide compensation mechanism (see Table 2) to ensure services reach all children in need.

(3) Social Collaboration Portal (Actor-Institution Coupling)

Dedicated functional modules are designed to promote more convenient participation of social forces (e.g., volunteer organizations, enterprises, foundations) in protection services for children in difficult circumstances through methods such as demand-supply contractual routing (e.g., government side publishes desensitized service packages; social side submits capability proof chains), forming a co-governance pattern of government leadership and social participation.

Table 2. Three-Tier Compensation Design for the Digital Divide in Remote Rural Areas

Compensation Level	Core Issue	Compensation Mechanism	Technical Implementation
Access Layer	Lack of network/terminals	Village-level service station terminals	Offline data package protocol
Access Layer	Lack of network/terminals	Feature phone data reporting	Offline data package protocol
Application Layer	Insufficient digital literacy	Dialect voice interaction	NLP dialect recognition
Application Layer	Low literacy rate	Pictorial operation guides	Low-literacy UI
Transmission Layer	Poor network stability	Offline collection modules	Breakpoint resumption + data compression
Transmission Layer	Poor network stability	Low-bandwidth optimization protocol	Breakpoint resumption + data compression

3.3 Cybernetic Logic of Three-Stage Control in Dual-Layer Architecture Collaboration

Drawing on cybernetics, the Provincial Intelligent Hub and the Municipal Service Response Hub do not operate in isolation but achieve dynamic collaboration through a "three-stage cybernetic loop", transforming traditional bureaucratic control into a more adaptive governance network.

Feedforward Control: Preventive control based on provincial preset rules and standards. The provincial platform formulates unified governance standards, data specifications, and operation templates, which the municipal service response hub configures and executes accordingly, playing a pre-guidance and normative role.

Concurrent Control: Real-time regulation achieved through technology during operation. The two-tier platforms achieve real-time data interaction and model adjustment through technologies such as federated learning and privacy-preserving computation, responding rapidly to emergencies or newly emerging demands.

Feedback Control: Corrective adjustments made to higher-level rules and models based on grassroots feedback. In response to information fed back by municipal-level service response hubs, such as data errors, implementation deviations, or changes in grassroots demands, the provincial-level platform promptly optimizes and adjusts the relevant indicator systems, algorithmic models, or governance rules, thereby forming a closed loop capable of autonomous continuous learning and improvement.

In summary, this architecture transforms the rigid control of a bureaucratic system into a resilient governance network characterized by "institutional empowerment—technological enablement—actor-driven agency." In particular, through the design of municipal-level service response hubs tailored to rural contexts, it can effectively mitigate the negative moderating effects of the digital divide [4,21].

4. Conclusion

In conclusion, this study not only attempts to provide a practical solution to the challenges facing child protection for children in difficult circumstances, but also theoretically explores the transformation pathway of public governance paradigms in the digital age. Specifically, it examines how, through deep synergy among institutions, technology, and actors, the bureaucratic fragmentation of information can be overcome while safeguarding citizens' fundamental rights (especially privacy rights), thereby activating the enthusiasm and initiative of multiple stakeholders. This provides an analytical model framework that can serve as a reference for the digital transformation of other highly sensitive public service domains. The two-tier governance framework constructed in this study—"provincial-level intelligent hub-municipal-level service response hub"—offers a systematic theoretical perspective for understanding and addressing data governance issues concerning children in difficult circumstances in urban and rural areas through threefold theoretical innovation: an institutional anti-fragmentation mechanism, a privacy computing empowerment pathway, and a three-dimensional trust generation model. The potential significance of this framework lies in its attempt to promote child assistance and welfare governance practices from traditional "experiential judgment" to more scientific "data-driven" approaches, from relatively "static management" to more adaptive "dynamic response," and from a relatively single "government-led" model to a "social symbiosis" pattern involving multiple stakeholders.

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