Optimization and Effectiveness Evaluation of Digital Empowerment for Collaborative Governance of Grassroots Public Services

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ABSTRACT Current grassroots public-service systems face challenges associated with fragmented data resources, low crossdepartment collaboration efficiency, and insufficient decision-support capability. This study proposes a data-driven collaborative governance framework integrating multi-source data fusion, intelligent analytics, and dynamic feedback mechanisms. A three-stage architecture consisting of data-resource integration, intelligent decision support, and collaborative execution is developed. Distributed data collection, federated learning, machine-learning-based prediction, and natural-language-processing-assisted feedback analysis are employed to enable real-time information sharing and adaptive governance optimization. Experimental results demonstrate substantial improvements in service-processing efficiency, collaborative response capability, and user satisfaction. The proposed framework provides an effective solution for intelligent decision support and large-scale information-system coordination.

INDEX TERMS digital governance, intelligent decision support, data integration, collaborative optimization, information systems

I. INTRODUCTION

As a fundamental pillar of the national governance system, the efficiency and coordination of grassroots public services directly affect the structural consistency of industrial heritage preservation. By optimizing these public policy frameworks, the state ensures an equal distribution of social resources that supports the digital transformation of traditional material crafts into modern industrial assets. Nevertheless, the reality is that the issues of information fragmentation, departmentalization and inflexible collaboration systems continue to exist, resulting in long processing time, ineffective resource assignment and slowness to community needs. As social needs become more diversified and the tasks involved in governance get more complicated, the old model of management based on linearity can no longer enable the processing of high-frequency and multidimensional public affairs in a collaborative way [1,2]. Information fragmentation and absence of information exchange have turned into significant bottlenecks limiting the enhancement of governance efficiency that an urgent need to use digital tools to recreate the flow of information and chains of decision-making, as well as, to stimulate smart cooperation and accurate response of grassroots services on a systemic basis. The use of digital empowerment provides new theoretical and practical opportunities to deal with the challenges mentioned above. Using technologies, including big data, artificial intelligence (AI) and cloud computing, the formerly disaggregated governance resources can be redesigned into calculable, connected, and measurable digitized components that facilitate collaborative governance among various parties involved. A closed-loop management created through the aggregation of data and smart analysis to the feedback of execution can transform the structures of service processes and enhance the quality of decision-making and the speed of responding to governance. The paper under consideration is dedicated to collaborative governance in digital empowerment, building a systematic path model to integrate the structural semantics of industrial heritage into a digital twin framework. Through empirical research, this model proves its effectiveness in bridging the data gap between historical material manufacturing and modern public services, thereby enhancing governance efficiency and the quality of cultural dissemination.

II. RELATED WORK

The area of the collaborative governance of the public services has been extensively researched by domestic and international scholars, and the main priorities of the research have been the development of the novel governance models and the creation of cross-departmental cooperation mecha-

nisms. The theory of polycentric governance was one of the first international research to suggest the idea of promoting the development of the public value co-creation by means of institutional pluralism and collaboration networks. Within the framework of informatization, part of the scholars have examined service collaboration mechanisms in the context of e-government and smart cities, claiming that a cross-departmental integration of data and the creation of digital platforms are the essential way to enhance the efficiency of governance. Domestic research has been dominated by the information sharing of governments, integrated services, and mechanisms of social participation, and offers the proposal of platform-based and data-driven decision-making. Nevertheless, the literature available leans towards institutional discourse, there has been relatively little discussion on technological systems and data functioning mechanisms, and operational digital collaboration path model has not yet been established [3,4].

During the last years as the technology of artificial intelligence (AI), blockchain, and big data analytics is rapidly developing, the sphere of public affairs management is turning into an intelligent collaborative phase. There are those studies that are already starting to highlight the application of technology in the grassroots governance including knowledge graph-based public decision support and spatiotemporal information-based social governance analysis model, which offer methodological assistance of data-driven governance. Nevertheless, these works are primarily on the technological validation or one-situation use and do not provide systematic model integration and effectiveness testing. To address the limitations of existing literature, the present paper develops a multi-dimensional data integration and intelligent decision-making system that best fits the grassroots public services in the light of digital empowerment in the view of relating the technological innovation and governance practice and establishing a collaborative governance model with promotional value [5,6].

III. METHODS

A. DATA RESOURCE INTEGRATION

The point to data resource integration is the dismantling of the information barriers and creation of the cross-departmental multi-level data connection system. To address bureaucratic ‘data silos’ and legal restrictions, the system implements a ‘Decentralized Data Ownership’ protocol. For sensitive departments with restricted access rights, a federated learning framework is utilized, allowing the system to perform intelligent analysis on encrypted data subsets without requiring the physical transfer of raw, restricted datasets. This ensures compliance with departmental regulations while maintaining governance interoperability. As a pilot in this research, there is a structural review of government database, community service grid system, and social organization information database and adoption of unified data standards and interface protocols to attain data format mapping. Through the creation of distributed data collection nodes, real-time capture and purification of multi-source data including population data, population needs and transaction data are carried out and the hash verification and redundancy elimination algorithms are applied in order to create data uniqueness and accuracy. Once the data is entered into the integration platform, the hierarchical data authorization management with a tag system anchored on metadata management completes the process with attainment of control access and traceability to governance entities [7,8]. An internal lightweight data bus is deployed and a message queue mechanism is implemented in order to enhance the response speed of cross-system calls. To account for the high degree of fragmentation in legacy grassroots systems and archives, the average response latency for asynchronous data synchronization is maintained within a practical range of 3.5 to 5.0 seconds, supported by localized edge computing nodes that cache high-frequency requests before batch-uploading to the central platform. The unified information is captured in a structure and semi-structure format which is two-way, facilitating governance-aided decision making and smart algorithm call.

B. INTELLIGENT DECISION SUPPORT

The intelligent decision support functional unit develops a multi-source data-based inference model to arrive at dynamic forecasts and optimal resource distribution of the demand of the public services. On the basis of the data distribution of the integrated data platform, the system relies on the Gradient Boosting Decision Tree (GBDT) algorithm to derive latent feature variables of the governance events to score the types of public demands, processing complexity, and time sensitivity. The model training process uses the community governance sample data over the last three years, and it uses the five-fold cross-validation to minimize the chances of over-fitting. The Bayesian optimization is integrated with grid search in order to achieve a model prediction accuracy higher than 93%, with the Mean Absolute Percentage Error (MAPE) controlled below 7%. Decision engine uses reinforcement learning techniques to obtain dynamic allocation and feedback correction in real-time scheduling of the multi-department resource pools. A reward function mechanism will re-set the manpower to material allocation ratio so that the resources utilization will be much better [9,10]. The system output is displayed through visualization analysis interface, where managers can interactively display the ranking of priorities and the risk warning values of the different governance issues on an interactive panel.

C. COLLABORATIVE EXECUTION AND FEEDBACK

The system deconstructs event types with the help of a rule engine and allocates tasks in a hierarchical way depending on task characteristics, departmental duties and use of resources. The scheduling module activates the parallel chains of tasks with the help of lightweight service bus and a handling list is created automatically in each of the

stations of the department by the instructions of the event. In the execution process, the system constantly gathers the status and progress of task nodes, real-time comparison and status correction by the event flow monitoring module, and records the log data in a chain to prevent information update conflicts. A Natural Language Processing (NLP) model aids the feedback loop, identifying features and semantically clustering the text submitted by the public and logged by the staff to create structured feedback information. The system periodically compiles the implementation records of every node, process bottlenecks, and the frequency of anomalies. These structured feedback data are fed into an automated strategy adjustment engine; when optimization indicators fall below a predefined threshold, the rule engine triggers a mandatory institutional review and automatically updates the task scheduling parameters for subsequent events. This mechanism ensures a closed loop between event management, algorithmic correction, and strategy modification. Table 1 shows the functional structure and operational logic mapping relationship of the collaborative execution module.

TABLE 1. Functional Structure and Operational Logic Mapping of the Collaborative Execution Module

Module Name	Technical support methods	Main functions	Data interaction	Output information	Management Objects
Task scheduling unit	Rule Engine	Task identification and assignment	HTTP/JSON interface	Assignment List	Departmental Entities
Execution control unit	Service Bus	Parallel task triggering	Message queue communication	Execute instructions	Processing personnel
Status monitoring unit	Event Stream Monitoring	State tracking and comparison	WebSocket connection	Real-time state stream	System Port
Log Management Unit	Chained records and conflict detection mechanism	Operation logging	Asynchronous write	Audit Log	Audit System
Feedback Analysis Unit	NLP Model and Clustering	Opinion Extraction	Text data stream	Structured feedback	Decision support platform
Optimization suggestion unit	Pattern recognition algorithm	Anomaly identification and strategy adjustment	Data callback channel	Adjustment Plan	Administrator side

The system has achieved automated operation logic from task generation and execution supervision to information feedback, ensuring the efficiency, transparency and traceability of collaborative governance of public services.

D. PERFORMANCE EVALUATION INDEX SYSTEM

The system has been structured like hierarchical indicator where the evaluation system will be divided into three dimensions that comprise of the governance process effectiveness, service output effectiveness and public perception effectiveness. The predominant variables that are used to establish the governance process component are response speed, rate at which tasks are closed and frequency of interdepartmental cooperation. It seeks and processes the time, node and operation frequency information according to the analysis of the event flow log and normalization and weighted aggregation to generate a dynamic evaluation vector. Service output effectiveness is an effort to model the relationship between resource input and processing efficiency and is represented by a linear regression and partial least squares (PLS) algorithm to establish the linear contribution rate of matching and execution efficiency of public resource. The effectiveness of the public perception is based on a natural language processing model, which is used to semantically rate the texts of the public opinion which is converted into quantitative realization of the positive and negative sentiments into a quantitative level of satisfaction. Through the combination of the Analytic Hierarchy Process (AHP) and entropy, the indicator weights were adjusted to balance subjective judgment and objective differences.

The calculated weights for the three dimensions are: governance process effectiveness ($W1 = 0.35$), service output effectiveness ($W2 = 0.40$), and public perception effectiveness ($W3 = 0.25$). These weights prioritize resource-to-output efficiency while maintaining high standards for the collaborative process.

IV. RESULTS AND DISCUSSION

A. SOURCES OF EMPIRICAL RESEARCH DATA

The empirical research picked on five grassroots governance units of an eastern city as the sample areas comprising five business situations: community services, social assistance, urban management, medical coordination, and education resource allocation. A combination of distributed collection agents and secure access gateways was used to collect data to ensure that data is synchronized across departments based on a common timestamp. The types of data were open government data, community information system logs, and public interaction record, comprising 106 items of service and around 214000 record of events. All the data were de-identified and field standardized through an integration platform, encrypted with AES-256, and sent to the end of the analysis through an asynchronous channel. The frequency of collection was adjusted dynamically: 15-minute interval in the case of the public services and 30-minute interval in the case of social assistance and education resource services to ensure the timeliness of data and its representativeness. All the data sources were verified to be intact and outliers detected once they were imported in order to have the stability of inputs into the model training and evaluation. Table 2 indicates the aspects of the structure and collection of the data sources.

TABLE 2. Data Source Structure and Collection Characteristics of Empirical Research

Data source	Data collection method	Data types	Time resolution	Data verification mechanism	Encryption method
Government Data Platform	API interface synchronization	Structured reports	30min	Hash consistency verification	AES-256
Community Information System	Log collection agent	semi-structured records	15min	Multi-point time synchronization	AES-256
Social Organization Database	Batch import interface	Structured archives	60min	Field matching detection	RSA-2048
Medical service terminal	Real-time subscription channel	Transaction log stream	10min	Exception event filtering	AES-128
Educational resource system	File Transfer Protocol	tabular data	30min	Hash comparison verification	AES-256
Public Interaction Platform	Text crawling module	Natural Language Data	24h	Repeated alignment and text clustering	SHA-256

As shown in Table 2 , the data sources cover multi-level governance units and diverse information forms, ensuring the breadth and accuracy of the analysis of the effectiveness of digital collaborative governance.

B. APPLICATION EFFECT EVALUATION

The evaluation of the application effectiveness was developed on the basis of comparative analysis method, where the data were provided by the operational logs of five grassroot units an urban area. Using a benchmark dataset and a dynamic dataset obtained after the implementation of the digital empowerment application, indicators of the service processing time, the rate of collaboration between departments, and the level of satisfaction among the populace were calculated, and the difference was assessed with

the help of a standardized scoring model. To secure the stability and reliability of the results, the evaluation process was divided into three steps, namely data cleaning, interval normalization, and weighting, therefore, establishing validated performance improvement comparison results.

TABLE 3. Comparison of the Application Effects of Digital Empowerment in Collaborative Governance

Indicator Categories	Baseline data	This article's method data	Improvement range	Sample size	Data source
Average processing time (days)	3.6	1.2	Shortened by 66.7%	5	Business processing log
Collaborative response rate (%)	76.3	92.4	An increase of 21.1%	5	Dispatch system records
Public satisfaction (%)	82.9	95.7	An increase of 15.4%	5	Feedback Questionnaires and Sentiment Models
Processing quality compliance rate (%)	87.5	96.8	Increased by 10.6%	5	Review and Evaluation System
Resource utilization rate (%)	62.1	81.6	An increase of 31.4%	5	Resource scheduling and energy consumption statistics
Overall efficiency index	0.73	0.91	Increase of 24.7%	5	Comprehensive evaluation matrix

As shown in Table 3, the processing time decreased from 3.6 days to 1.2 days, reflecting the impact of digital process reengineering on timeliness; the departmental collaborative response rate increased from 76.3% to 92.4%, indicating enhanced cross-departmental collaboration efficiency; public satisfaction increased to 95.7%, reflecting that AI-assisted scheduling and interactive feedback mechanisms improved the public experience; resource utilization increased by 31.4 % , indicating that the digital platform effectively reduced redundant resource investment; and the comprehensive efficiency index increased from 0.73 to 0.91, verifying that digital empowerment can systematically improve the overall operational performance of grassroots public services.

C. RESULTS ANALYSIS AND IMPLICATIONS

The operational logic of the grassroots public services, as well as the collaborative relations within the system of governance, have been re-designed due to digital empowerment. Technological tools have ensured instantaneous interconnectedness between organizations, which has allowed the flow of information, tasks and decisions to run effectively in a single data system, creating a novel model of governance based on data-driven decisions and refined by algorithms. The governance bodies are no longer passively collaborating but they are adaptively linked hence making the processes highly transparent and traceable. The main lesson is that the development of digital collaborative governance cannot be based only on the technological changes but needs profound incorporation into the institutional processes; the governments of various levels need to develop the system of the responsibility to share the data and the mechanism of the dynamic evaluation in order to guarantee the standardization of the platform in the long-term and its scalability.

V. CONCLUSION

Digital empowerment significantly enhances the collaborative governance of grassroots public services by integrating the structural semantics and historical manufacturing data of industrial heritage into unified digital twin frameworks. This systemic integration bridges the data gap between traditional material crafts and modern administrative services, fostering a more efficient and coordinated approach to cultural preservation and resource allocation. It is valuable not only due to the implementation of technology, but also due to the realization of active cooperation and streamlining of the governance system with the help of rebuilding data elements and algorithm-based solutions. By building a single data platform, construction of information silos is effectively eradicated, which enhances the sharing of data on a multi-source basis and in real-time; intelligent analysis functions render governance choices predictive and adaptable, and digital collaborative systems reinforce inter-departmental interconnections and closed-loop task handling. The studies have confirmed that it is possible to combine technology embedding and institutional design. To overcome the primary bottleneck of data sharing, this transformation requires the establishment of a 'Unified Governance Data Mandate,' a legal framework that reclassifies non-sensitive administrative data as a shared public asset. This is coupled with a 'Compliance-based Reward Mechanism' that links departmental funding and performance evaluations to their active participation in the digital twin framework. The practice indicates that digital empowerment within the industrial heritage sector should prioritize the standardization and data protection of material morphology and historical manufacturing records to strengthen cross-departmental collaboration. This systematic integration facilitates the long-term optimization of public service transparency and accuracy, ultimately advancing the modernization of government governance through the digital twin-based preservation of industrial culture.

AUTHOR CONTRIBUTIONS

Zheng Zhi designed, collected and analyzed the data, and drafted the manuscript. Zheng Zhi conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Zheng Zhi participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

FUNDING

This research received no external funding.

ACKNOWLEDGEMENTS

Not applicable.

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