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Research on the Aging-Adaptive Service Mechanism of AI Librarians in Libraries under Human-Machine Collaboration Mode

Tianling Guan[1,a,*]

[1]*Library, Guangdong Ocean University, Yangjiang, China*
[a]*gtl@gdou.edu.cn*
**Corresponding author*

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Abstract: Artificial intelligence is driving libraries into a new phase of human-machine collaborative services. From a purely theoretical perspective, this paper defines the core concepts of human-machine collaboration mode, library AI librarians, and aging-adaptive services. Supported by theories such as the digital divide and collaborative governance, it analyzes four major theoretical dilemmas in this field and their root causes, including cognitive biases in needs assessment. Guided by the principle of demand orientation, a four-dimensional closed-loop service mechanism encompassing stakeholders, needs, technology, and rules is constructed. Optimization pathways and a support system are proposed. The study enriches relevant theories, provides theoretical guidance for libraries to balance technological empowerment with humanistic care and promote equal access to public cultural services, and identifies research limitations and future directions.

1. Introduction

1.1. Research Background

China has entered a stage of deep aging, with the population aged 60 and above exceeding 21% of the total by the end of 2024[1]. While cultural and digital demands among older adults are rising, the digital divide manifests in multiple dimensions—including gaps in hardware access, skills, and cognitive understanding, placing this group at risk of exclusion from digital library services. Optimizing aging-adaptive services has thus become a central task for the high-quality development of libraries.

Artificial intelligence is propelling library services into a new phase of human-machine collaboration. AI librarians, with their standardized and around-the-clock capabilities, compensate for shortcomings in traditional services, while human librarians contribute emotional care and humanistic guidance to refine AI-driven offerings. Their synergy forms the core of service innovation, and relevant policies provide clear direction for constructing an aging-adaptive service mechanism for AI librarians [2].

This study carries both theoretical and practical significance. It not only fills a systematic

theoretical gap in the integration of AI librarians and aging-adaptive services, thereby enriching interdisciplinary research, but also offers logical guidance for libraries to avoid service deviations and collaboration imbalances. By harmonizing technological empowerment with humanistic care, the research supports the realization of equitable public cultural services.

1.2. Current Research Status

Research on human-machine collaboration and age-friendly services in libraries outside China commenced earlier and has achieved greater theoretical maturity. In the domain of human-machine collaboration, following the widespread adoption of collaborative governance theory, a complementary framework has been established where AI handles standardized basic services, while traditional librarians focus on personalized emotional support. Research on services for older adults primarily revolves around service inclusivity and the enhancement of digital literacy; however, studies specifically addressing mechanisms for tailoring AI librarians to the needs of older adults remain relatively fragmented.

Domestic research in this area has accelerated in recent years but remains constrained by significant limitations. Studies on AI librarians predominantly emphasize functional definition and classification, lacking in-depth exploration of authority distribution and operational logic within human-machine collaboration. Research on age-friendly services is often constrained by specific case studies, resulting in fragmented theoretical frameworks, and ongoing debates concerning the balance between AI-driven and traditional services remain unresolved. Current research exhibits three major gaps: dispersed perspectives, insufficient theoretical depth, and a lack of interdisciplinary integration.

The integration of artificial intelligence is propelling library services into a new phase characterized by human-machine collaboration. AI librarians complement traditional services by offering standardization and 24/7 availability, whereas traditional librarians address the shortcomings of AI by providing emotional care and humanistic guidance. Their synergy constitutes the core of service innovation, and relevant policies provide clear guidance for constructing age-friendly service mechanisms involving AI librarians in libraries. This study adopts a purely theoretical perspective to develop a dedicated mechanism, aiming to address the deficiencies present in existing research.

1.3. Research Content

The core content of this study encompasses four key dimensions: defining the modes of human-AI collaboration, the role of AI librarians, and the core concepts of age-friendly services, thereby clarifying their interrelationships and theoretical boundaries; synthesizing key theories such as the digital divide and collaborative governance to construct a supportive framework; analyzing the theoretical challenges and underlying causes of providing age-friendly services through AI librarians within human-AI collaborative settings; and ultimately, developing a scientific service mechanism, outlining optimization pathways and theoretical safeguards. The research employs three core methodologies: the literature research method systematically reviews core academic literature and policy documents, both domestic and international, to identify achievements, debates, and gaps, thereby establishing the theoretical foundation; the inductive-deductive method extracts key mechanism components and constructs a logical framework, ensuring theoretical coherence; the comparative research method contrasts theoretical outcomes and frameworks from different contexts, providing diverse references for mechanism development.

The innovation and focal challenges of this study are clearly defined. Its innovation lies in transcending the limitations of mixed theoretical and practical approaches, establishing a dedicated mechanism based purely on theoretical grounds, and integrating multidisciplinary theories to clarify the dual-agent relationship and construct a multi-agent collaborative framework. The principal

challenges focus on two aspects: balancing theoretical rigor with practical applicability while ensuring the mechanism is both logically coherent and pragmatically valuable; and effectively integrating multidisciplinary theories to reconcile logical disparities and contextual conflicts among them, thereby building a unified theoretical support system.

2. Core Concepts and Theoretical Foundations

2.1. Definition of Core Concepts

The Human-Machine Collaboration Mode refers to a system formed through the division of authority and responsibilities, information exchange, and functional complementarity between humans and artificial intelligence, each leveraging their own strengths. Its core characteristics are complementarity, synergy, and dynamism. It encompasses three dimensions: division of labor, complementarity, and linkage, which respectively correspond to defining task boundaries, superimposing human and machine advantages, and adapting roles dynamically. This aligns with the dual demands for efficiency and humanistic care in library services for older adults [3].

AI Librarian is a virtual agent that utilizes AI technology to integrate resources, processes, and data, capable of autonomously performing basic services. It is distinct from traditional librarians and general-purpose AI tools. Its functions are limited to standardized tasks such as intelligent inquiry and literature retrieval/push. Services requiring humanistic judgment, such as emotional support and complex decision-making, necessitate collaboration with traditional librarians. Its service forms must be adapted to the elderly population, for example, through voice interaction and simplified operations [4].

Library Aging-Adaptive Services are centered on inclusive and humanistic care, optimizing services to fit the physiological and psychological characteristics of the elderly population. In the digital context, its core demand has shifted from mere hardware adaptation to the collaborative adaptation of intelligent and traditional services. This involves retaining traditional services like physical borrowing and manual consultation, while simultaneously optimizing the senior-friendliness of intelligent services through AI. The goal is to prevent the exclusion of older adults due to insufficient digital skills, thereby achieving the objective of "accessible technology and warm-hearted service."

2.2. Core Theoretical Support

The Digital Divide Theory is central to analyzing the challenges older adults face with AI services. It points out that the divide manifests in three progressive forms: access, skills, and cognition. In the context of library AI services, the access divide is reflected in the insufficient ability of older adults to obtain devices and network resources; the skills divide refers to deficiencies in operational and interactive abilities; the cognitive divide involves a lack of trust in and difficulty understanding AI technology. This theory clarifies the need to bridge these gaps through technological adaptation and human-machine collaboration to achieve effective service reach [5]. The Collaborative Governance Theory provides support for defining human-machine relationships. Its core lies in multiple agents integrating resources and dividing responsibilities based on shared goals. Applied to libraries, AI and traditional librarians are equal collaborative agents: AI undertakes efficiency improvement in basic, standardized services, while librarians focus on personalized services and humanistic guidance. Information sharing and linkage between these agents provides the core logic for mechanism design. The User Needs Theory is the starting point for mechanism construction, requiring services to center on the genuine needs of the elderly population. These needs are categorized into four levels: basic function, safety security, emotional companionship, and personalized demands. This necessitates that

the mechanism possess the capability for precise and diversified service provision. The Technology Acceptance Model (TAM) provides a basis for aging-adaptive design. Perceived ease of use has the most significant impact on the elderly population. It is necessary to simplify AI operations, optimize interaction, and rely on librarian guidance to enhance intention to use. The Service Quality Management Theory provides an evaluation framework, controlling quality across dimensions such as reliability and responsiveness, which runs through the entire mechanism operation [6][7].

3. Theoretical Dilemmas and Their Root Causes in Aging-Adaptive Services of Library AI Librarians

3.1. Core Theoretical Dilemmas

The Technology Adaptability Dilemma constitutes the central conflict, stemming from the inherent clash between the standardized nature of AI and the personalized needs of the elderly. AI's core advantage lies in standardized, scalable services, with interaction logic designed on general-purpose models. This makes it difficult to adapt to the significant variations among the elderly in physiological traits, digital literacy, and psychological states, leading to a "one-size-fits-none" predicament: overly complex operations exceed the capabilities of those with low skills, while overly simplified functions fail to meet the needs of those with higher skills. This hinders precise service delivery and may ultimately diminish service value.

The Human-Machine Collaboration Logic Dilemma manifests as a dual bottleneck of ambiguous authority/responsibility and inefficient service handoffs. Existing theories lack a dedicated collaborative framework for libraries. Unclear delineation of roles and responsibilities between the two agents (AI and human librarians) can lead to either "techno-centrism," which neglects humanistic values, or an adherence to tradition that weakens AI's efficacy, often resulting in overlapping duties or service gaps. Furthermore, the absence of a robust mechanism for real-time information sharing and linkage between human and machine agents means service information cannot flow seamlessly, causing disconnects that impede the maximization of collaborative effectiveness.

The Service Provision Logic Dilemma arises from the imbalance between homogenized content and differentiated demand. Prevailing theories on aging-adaptive services often focus on universal designs like simplified interfaces and voice interaction, lacking a deep deconstruction of the diverse needs within the elderly population. These needs extend into the socio-cultural realm: elderly individuals with low digital literacy prioritize basic services and skill guidance, while those with high digital literacy seek personalized resources and in-depth services. The disconnect between homogeneous supply and heterogeneous demand deviates from the "demand-oriented" principle.

The Theoretical System Dilemma is the fundamental constraint on deepening research, characterized by fragmentation and insufficient interdisciplinary integration. Existing studies are often confined to single dimensions, failing to incorporate core elements like technological adaptation and human-machine collaboration into a unified system, resulting in frameworks that lack cohesiveness. While this topic necessitates integrating multidisciplinary resources, current research remains limited to singular disciplinary perspectives. The lack of cross-disciplinary integration weakens the explanatory power of the theories and hampers the construction of a scientifically sound and comprehensive service mechanism.

3.2. Root Causes of the Dilemmas

Demand Cognition Bias is the fundamental root cause. Existing research often treats the elderly population as a homogeneous whole, lacking in-depth deconstruction of their stratified needs, differentiating characteristics, and influencing factors, and failing to construct accurate demand

profiles. On one hand, demand identification is one-sided, overly focusing on basic physiological and skill-related needs while neglecting socio-emotional needs such as companionship and personalized cultural engagement. On the other hand, insufficient consideration of variables like age, gender, educational background, and digital literacy leads to service theories built on demand being disconnected from reality. This lays the groundwork for problems in both technological adaptation and the design of collaborative logic.

The Mismatch Between Technology and Service Adaptation stems from a deviation in theoretical orientation. Some research falls into "techno-centrism," prioritizing the advancement of AI itself, overemphasizing functional upgrades while neglecting the genuine needs and user experience of the elderly. This creates a disconnect between technology and demand. Scholars such as Huang Ruhua have pointed out that the core ethics of intelligent library services are "human centric." Deviating from this orientation inevitably results in insufficient aging-adaptability. Concurrently, academic understanding of AI's aging-adaptability remains superficial, often limited to surface-level operational simplifications without systematic adaptation design that incorporates the physiological characteristics and cognitive habits of the elderly. This further exacerbates the technological adaptation dilemma.

The Imperfection of Human-Machine Collaboration Theory arises from the lack of dedicated adaptation to the library context. Existing collaborative governance theory originates from the field of public administration, suited for collaboration among multiple human actors. It struggles to adapt to the unique "human-AI" relationship, lacking targeted explanations for defining AI's authority/responsibility and functional positioning. Domestic research often merely applies these general theories without innovating based on the public, humanistic nature of libraries and the needs of the elderly. This leads to a disconnect between theory and context, preventing clear guidance for dual-agent collaboration and resulting in the collaborative logic dilemma.

Insufficient Multidisciplinary Integration exacerbates the fragmentation of the theoretical system. This topic requires interdisciplinary support, yet current research is confined to singular perspectives: Library and Information Science focus on service optimization but lacks understanding of AI technology; Computer Science concentrates on technological development but overlooks elderly needs and ethics; Gerontology examines population characteristics but lacks analysis adapted to the library setting. The absence of interdisciplinary research prevents the integration of theoretical resources, making it difficult to construct a comprehensive, multi-dimensional theoretical framework for the entire service process. This leads to insufficient explanatory power and systemic rigor in the theory, ultimately failing to support the scientific construction of a service mechanism.

4. Construction of the Aging-Adaptive Service Mechanism for Library AI Librarians

4.1. Principles for Mechanism Construction

The Demand-Oriented Principle serves as the core logical starting point. It centers on the genuine needs of the elderly population, balancing inclusivity with differentiation. It emphasizes the precise deconstruction of demand hierarchies to avoid homogeneous service provision, thereby constructing a targeted service system. The principle requires incorporating four key demand dimensions: basic functionality, safety security, emotional companionship, and personalization. A stratified adaptation mechanism must be established to provide differentiated solutions for elderly individuals with varying digital literacy and physiological characteristics. This approach ensures accessibility for low-skill groups while addressing the personalized demands of high-skill groups. The Human-Machine Collaboration Optimization Principle focuses on defining the functions of dual agents. Based on collaborative governance theory, it establishes the equal status of both AI and human librarians, moving beyond a single-agent-dominant mindset. AI undertakes the efficiency

enhancement of standardized, basic services, while traditional librarians lead in emotional support, humanistic care, and skill guidance. Concurrently, a dynamic adjustment mechanism should be established to optimize role positioning according to specific scenarios and needs, achieving complementary advantages and efficient synergy.

The Theoretical Self-Consistency Principle ensures the scientific rigor of the mechanism. It requires seamless integration of all modules, incorporating core theories such as the digital divide and technology acceptance. This ensures every component is theoretically grounded and free of logical contradictions, forming a closed loop of "demand identification – service provision – human-machine collaboration – dynamic optimization." The mechanism must align with both core library values and the characteristic needs of the elderly. The Dynamic Adaptation Principle emphasizes the mechanism's adaptability. It must accommodate the iterative evolution of AI technology and the changing needs of the elderly population. The design should incorporate room for optimization and establish a continuous "optimization – feedback – re-optimization" system. This allows for the dynamic adjustment of collaboration logic, service content, and technical standards, ensuring long-term applicability.

4.2. Core Elements and Architecture of the Mechanism

This mechanism centers on four core elements: the Actor, Demand, Technology, and Rule dimensions, which together support the orderly operation of the entire system. The Actor Dimension defines the roles of the dual agents: the AI Librarian provides basic services according to aging-adaptive standards, while the traditional librarian is responsible for skill guidance, emotional care, and handling complex issues. This establishes a collaborative relationship characterized by “AI supplementing efficiency, humans supplementing warmth.” The Demand Dimension forms the logical starting point, decomposing needs into four layers basic, security, emotional, and personalized, which anchors the direction of service provision. The Technology Dimension emphasizes that aging-adaptive AI must feature simplicity, stability, security, and user-friendly interaction, focusing on basic services while clearly defining its application boundaries. The Rule Dimension, through the division of authority and responsibilities, process standardization, and “human-centric” guidelines, prevents responsibility gaps and mitigates ethical risks.

Based on these core elements, a four-dimensional closed-loop architecture is constructed: The Demand Identification and Translation Mechanism, grounded in user needs theory, translates elderly needs into service and technical objectives; The Human-Machine Collaborative Operation Mechanism adopts a model of “AI-led basics, Human-led precision and Joint emergency response,” achieving seamless connection through information sharing; The Aging-Adaptive Service Provision Mechanism optimizes content, form, and language in an all-round manner, balancing standardization and personalization; The Dynamic Optimization Mechanism, in response to technological iteration and evolving needs, continuously refines the architecture through theoretical reflection and interdisciplinary integration, ensuring the mechanism's long-term adaptability.

5. Theoretical Optimization and Support System for the Mechanism

5.1. Theoretical Optimization Pathways

Strengthening multidisciplinary theoretical integration constitutes a core pathway for enhancing the depth of the mechanism. It necessitates the integration of resources from Library and Information Science, Gerontology, Philosophy of Technology, Public Administration, and other fields to enrich the theoretical foundation. This involves introducing Gerontological research findings on physiology and psychology to optimize demand identification models and service adaptation design;

incorporating Social Inclusion Theory to improve support for service inclusivity; applying Technology Ethics theories to regulate the boundaries of AI application; and adopting the theory of Equalization of Public Services to reinforce the public value orientation of the mechanism. Through the organic fusion of multiple disciplines, the limitations of singular perspectives can be transcended, enabling the construction of a multidimensional and systematic theoretical support framework.[8]

Optimizing the logic of human-machine collaboration requires refining the division of authority and responsibilities to build an operable theoretical framework. Grounded in Collaborative Governance Theory, the specific authority and responsibilities of AI and human staff across different service scenarios and demand levels must be clearly defined to avoid ambiguities. A "bidirectional linkage" logic should be established, ensuring not only the flow of information from AI to humans but also facilitating human guidance for AI functional optimization, thereby forming a mutually supportive relationship. Concurrently, introducing theories such as Game Theory and Collaborative Equilibrium can help analyze potential conflicts and construct coordination mechanisms to ensure the stable operation of the collaborative relationship.

Focusing on demand precision involves refining the theoretical profile of elderly population needs. Building upon User Needs Theory and Digital Divide Theory, additional dimensions such as hobbies and cultural background should be incorporated to construct a comprehensive profile model. Introducing Demand Forecasting Theory can allow for the projection of future demand trends, enabling proactive optimization of service provision and collaborative logic. To address the differing needs among various subgroups of the elderly population, a stratified adaptation system should be established to achieve precise matching between demand and service, thereby overcoming the dilemma of homogenization.

5.2. Theoretical Support System

The foundation of this framework lies in establishing a multidisciplinary support network. By integrating core theories such as the digital divide and collaborative governance, a comprehensive theoretical system is constructed to underpin all aspects of the service mechanism. Research on human–machine collaboration and age-friendly services is further deepened to dynamically enhance this system in response to technological and societal changes. A verification mechanism incorporating peer review and theoretical reflection ensures the logical rigor and scientific validity of the overall framework.

Techno-ethical Framework, ethical boundaries for AI-enabled aging services are defined through four guiding principles: Adherence to a human-centered approach, prioritizing the needs of older adults in technology design and application; Strict privacy protection, including standardized data collection, storage, usage protocols, and enhanced encryption measures; Assurance of service transparency and explainability, enabling clear traceability of AI decision-making to foster trust among elderly users; Establishment of a technical early-warning mechanism to monitor and mitigate system malfunctions and ethical conflicts, thereby reducing risks of technological alienation.

Service Philosophy, centered on “inclusive universalism and human–machine symbiosis,” this philosophy reaffirms libraries’ public-service orientation and prioritizes older adults’ rights. It rejects reductionist views of aging adaptation, instead integrating humanistic care with technical collaboration. Promoting this approach guides practitioner conduct and enhances older adults’ trust in AI-enhanced services.

Institutional Structure, Grounding in public administration theory, the institutional framework establishes standards for service delivery, human–machine collaboration, quality assessment, and staff training. It defines operational protocols, information-sharing mechanisms, multidimensional evaluation systems, and competency requirements for librarians, thereby providing normative support

for effective mechanism implementation.

6. Conclusion

This study, grounded in a purely theoretical perspective, explores the aging-adaptive service mechanism for library AI librarians under the human-machine collaboration mode, yielding three core conclusions. First, this field faces four major dilemmas, rooted in issues such as demand cognition bias, which constrains both theoretical and practical development. Second, mechanism construction must adhere to four foundational principles, supported by four core elements; a four-dimensional closed-loop architecture can address the existing dilemmas and effectively integrate technology with humanistic care. Third, mechanism optimization relies on three key pathways and the establishment of a four-part support system to ensure scientific adaptability.

This research fills a pure theoretical gap in the integration of human-machine collaboration and aging-adaptive library services, providing a reference for subsequent studies while also offering guidance for libraries to optimize service provision and promote the equalization of public cultural services. The study has limitations, including a lack of empirical data for validation and insufficient anticipation of AI technological iteration.

Future research can develop in three directions: first, validating and refining the mechanism through case-based empirical studies; second, focusing on emerging technologies such as generative AI to expand theoretical boundaries; third, strengthening cross-regional comparative research to enhance the mechanism's generalizability, and drawing on international research to refine China's theoretical framework.

References

[1] Pi, L. (2025). The 2024 National Aging Development Bulletin released. [Public Welfare Times].
[2] Liu, Z. W. (2025). Research on the symbiotic service of "human + AI" dual librarians in the digital intelligence era. Library Work and Study, 357(11), 17–25.
[3] Liu, M. J. (2025). Human–machine collaborative models for content filtering in the era of information overload and their optimization. Publishing Panorama, 481(7), 92–98.
[4] Hu, Y. C. (2025). Application and practice of library AI librarians in bridging the digital divide among the elderly. Science & Technology Information, 23(10), 243–245.
[5] Hu, X. Y. (2024). Lack and penetration of media literacy among the silver-haired group in the new media era: A discussion from the perspective of the digital divide theory. Journalism Communication, 466(1), 49–51.
[6] Li, J. Q., Shao, X. F., & Liu, W. Y. (2025). Research on the smart learning pathways of older adults based on the technology acceptance model theory. Adult Education, 45(9), 33–39.
[7] An, H. (2024). Research on factors influencing the willingness of elderly groups to use artificial intelligence. Modern Marketing, 846(18), 36–38.
[8] Li, Y. (2021). Research on health information services for the elderly in community libraries[Master's thesis, Fujian Normal University].