Research on Sustainable Support Mechanisms for Long-term Preservation of Digital Scholarly Resources: Postprint

Authors: Zheng Jiancheng, Zhang Xiaolin, Zhao Yan, Wu Zhenxin, Yin Gaolei, Xiao Man, Chen Xiujuan

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Abstract

【Purpose】 To analyze the sustainability challenges in the long-term preservation of digital literature resources and advance the sustainable development of long-term preservation services. 【Method】 Systematically analyze relevant domestic and international literature, sort out the sustainability framework for long-term preservation, analyze the system of issues including trustworthiness certification and economic support, and examine and organize the implementation mechanisms for trustworthiness certification and economic investment in long-term preservation. 【Results】 Propose specific recommendations for developing sustainable support mechanisms for the long-term preservation of digital literature resources. 【Limitations】 Only a brief overview of economic support models and related research for the long-term preservation of digital literature resources is provided, which requires more in-depth discussion. 【Conclusion】The sustainability of long-term preservation of digital literature resources includes format sustainability, system sustainability, and service sustainability; service sustainability involves management, economic, and political sustainability requirements, and specific recommendations for strengthening the sustainability development of long-term preservation are proposed.

Full Text

Preamble

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Sustainable Support Mechanisms for Long-Term Preservation of Digital Publications

Zheng Jiancheng[1], Zhang Xiaolin[1], Zhao Yan[1,2], Wu Zhenxin[1], Yin Gaolei[1,2], Xiao Man[1], Chen Xiujuan[1,2]

[1](National Science Library, Chinese Academy of Sciences, Beijing 100190, China)
[2](University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract

[**Objective**] This paper analyzes the sustainability challenges in long-term preservation of digital publications and promotes the development of sustainable preservation services. [**Methods**] Through systematic analysis of relevant literature both domestically and internationally, this study constructs a framework for sustainability issues in digital preservation, examines systems for trustworthy certification and economic support, and analyzes implementation mechanisms for trustworthy certification and economic investment in preservation activities. [**Results**] The paper proposes specific recommendations for constructing sustainable support mechanisms for digital preservation. [**Limitations**] The paper provides only a brief overview of economic support models and related research, which requires more in-depth discussion. [**Conclusions**] The sustainability of digital publications encompasses format sustainability, system sustainability, and service sustainability. Service sustainability involves requirements for managerial, economic, and political sustainability, and the paper puts forward concrete suggestions for strengthening sustainability construction.

Keywords: Digital publications; Long-term preservation; Sustainability; Support mechanism

Classification Number: G250

Long-term preservation of digital publications serves as a risk prevention mechanism to ensure that preserved resources remain accessible and usable under any technological, economic, market, or managerial conditions. However, it involves complex rights, technical, system, and management factors and requires substantial and sustained economic investment, thus facing its own sustainability challenges.

1.1 Sustainability of Digital Content Formats

Content format constitutes the fundamental structure for expressing, storing, and exchanging digital object content, structure, and relationships, and represents a necessary factor for digital objects to be identifiable, renderable, understandable, and usable, as well as a prerequisite for correctly comprehending the content contained in digital objects. Nevertheless, different and even competing formats exist for the same type of digital object, with new formats continuously emerging while old ones become obsolete. For instance, the PRONOM system has registered over 1,400 digital file formats, including 36 with the ".pdf" extension alone, with 24 new formats added during the two-month period from July 27

to September 27, 2016. The Library of Congress' s digital format sustainability program lists eight categories of digital objects comprising approximately 350 formats, including 51 text formats and 90 static image formats. Consequently, selecting appropriate formats for long-term preservation and accurately identifying and effectively interpreting various content formats (including obsolete ones) has become a critical issue.

Addressing this challenge requires, on one hand, selecting content formats that can be reliably utilized over the long term during the preservation or even procurement stage, and on the other hand, registering digital format standards and specifications to support format validation. To this end, the Library of Congress has proposed seven evaluation criteria for digital format sustainability: Disclosure, Adoption, Transparency, Self-Documentation, External Dependencies, Impact of Patents, and Technical Protection Mechanisms. Zhang Zhixiong and colleagues have also synthesized eight principles for digital format selection based on domestic and international research: suitability for multiple environments, support for migration from proprietary to general environments, high degree of standardization, broad industry or user support, strong extensibility, ability to be authentically and completely read and understood by users, capability to record file processing history, and self-verification ability.

To support digital format registration, discovery, and interpretation, Harvard University established the Global Digital Format Registry and the University of California Digital Library created the Unified Digital Format Registry, though only the UK' s National Archives PRONOM system remains operational today. As digital publications become increasingly rich-media and linked, identifying complex digital object formats and versions has also become a challenge for preservation systems.

Establishing a comprehensive format management strategy that includes format evaluation, selection, registration, description, identification, validation, and conversion, and continuously updating, revising, and improving this strategy as formats evolve, constitutes an important foundation for the sustainability of digital publication preservation.

1.2 Sustainability of Preservation Systems

Beyond the inherent vulnerabilities of digital information (such as susceptibility to deletion, modification, loss, bit decay, and software dependency), digital resources also face external threats (natural disasters, attacks, technical failures, managerial negligence, etc.). Therefore, digital preservation systems require higher standards of information security management and must comply with relevant international and domestic information security management standards, such as the ISO Information Security Management Systems standard and China' s information security level protection standards (see Table 1), while also meeting long-term preservation trustworthy system certification standards like the ISO Open Archival Information System standard and the ISO Audit

and Certification of Trustworthy Digital Repositories.

Preservation system sustainability encompasses hardware capacity scaling, sustainable software use, technical reliability, system manageability, and system security auditability, preventing preservation systems from becoming unavailable, non-operational, or unmanageable due to outdated software or supporting infrastructure, inability to update hardware or upgrade capabilities according to needs, functional defects, hacker attacks, or staff turnover.

Sustainability of preservation systems requires not only establishing a reliable long-term preservation technical architecture and following trustworthy standards to ensure comprehensive support for all tasks in the preservation lifecycle, but also maintaining compatibility with stakeholder systems and related technical processes and with future technological changes.

1.3 Sustainability of Preservation Services

Long-term preservation services constitute a systematic engineering endeavor that requires reliable planning, rights management, technical architecture, organizational mechanisms, economic investment, and public service policies, as well as public audit and certification of preservation services and necessary succession mechanisms to support reliable and sustainable operation of the entire preservation service. The sustainability of preservation services involves not only technical issues but also managerial, business, and "political" considerations.

(1) Managerial Sustainability of Long-Term Preservation

Managerial sustainability involves a series of management systems throughout the preservation process, including preservation rights management, process management, personnel management, economic management, and risk management, along with corresponding implementation norms (see Figure 1 [Figure 1: see original paper]), to ensure reliable operation of preservation systems under any circumstances. Long-term preservation reflects the will of institutions, organizations, and even nations, requiring the establishment of long-term effective institutionalized, regulatory, and mandatory management mechanisms to ensure that preservation services are not affected by institutional or personnel changes. The management system for long-term preservation requires: clear division of responsibilities and authority in the management responsibility system (including planning, management, and operational levels); highly competent responsibility teams with adequate resources; sound management systems and implementation norms for overall processes and individual links; and the capability for accurate traceability, dynamic assessment, rapid response, timely processing, and continuous improvement of operational processes and management operations.

(2) Economic Sustainability of Long-Term Preservation

Long-term preservation services involve complex technical infrastructure and long-term operational activities requiring sustained and adequate economic sup-

port. Specific economic support mechanisms depend on different preservation service models and corresponding cost burden arrangements, which must also consider market supply of preservation services. The report *Sustainable Economics for a Digital Planet: Ensuring Long-Term Access to Digital Information* emphasizes that both centralized and distributed preservation models must ensure adequate economic support. Lavoie, one of the co-chairs of the report's task force, notes that economic sustainability faces several challenges: preservation activities often adopt short-term "project-based" funding that emphasizes initial system construction but neglects long-term maintenance; preservation lacks clear responsibility and is often considered "someone else's problem," resulting in insufficient funding and "free-rider" problems; lack of incentives for preservation actors; lack of coordination among stakeholder preservation activities; and difficulties in assessing preservation costs and benefits and conducting reasonable cost analysis for different preservation models and operational mechanisms.

The EU Seventh Framework Programme's "Collaboration to Clarify the Costs of Curation" project report notes that economic sustainability strategies for digital preservation must consider the economic lifecycle of preservation, key preservation entities (digital assets, preservation processes, stakeholders and their relationships, preservation operating environment), and sustainability conditions. Sustainable strategies must coordinate economic factors to ensure adequate resources throughout the preservation lifecycle. Decision-makers must select factors affecting sustainability (such as preserved resources, preservation models, incentive mechanisms for resource investment or sharing, resource allocation and effectiveness verification mechanisms) and fully anticipate major economic uncertainties with clear remedial measures.

(3) "Political" Sustainability of Long-Term Preservation

"Politics" refers to activities through which stakeholders use institutional arrangements to satisfy or protect their own or certain parties' interests. Any preservation service operates in a complex interest environment, and "political" sustainability seeks institutional arrangements that ensure preservation services receive corresponding political, legal, and managerial support. These arrangements should: facilitate maximum balance of legitimate interests among all stakeholders (including preservation actors' rights to archive, process, serve, and cooperatively preserve; providers' rights to attribution, integrity, accuracy, and security; cooperative preservation partners' rights to supervision, service, and audit; and end users' rights to guaranteed access and information security); facilitate maximum trust and support from preservation service recipients (including subscribing institutions and their users), involving whether digital content is accurately and completely preserved, whether preservation systems are secure and reliable, whether management mechanisms are sound and standardized, and whether services receive adequate resource support; and effectively constrain any stakeholder's possible misconduct or negligence, such as reasonably limiting preservation actors' service provision beyond content or user scope that harms providers, while preventing providers from restricting preservation rights

through contractual traps, technical barriers, or procedural neglect.

2.1 Public Certification Requirements for Trustworthiness

For long-term preservation of digital publications to gain the trust of service recipients, investors, and even future users that preserved resources will be completely preserved and available at any time in the future, preservation activities must possess trustworthiness—encompassing trustworthiness of preserved digital objects, preservation system infrastructure, and preservation activities and management mechanisms. Trustworthiness cannot rely on preservation institutions' goodwill or self-certification but must be verifiable and evaluable, requiring the development of trustworthy certification standards, indicator systems, and certification processes, particularly public recognition, open implementation, and public verification mechanisms. Due to the complexity of preservation systems and processes, trustworthy certification often requires specialized certification bodies to conduct audits according to established procedures and norms, following international high-standard trustworthiness indicator systems, establishing open audit and certification mechanisms aligned with best market practices, and creating mechanisms to utilize public audit results to improve preservation operations.

2.2 Practices in Trustworthy Certification for Long-Term Preservation

The Trustworthy Repositories Audit & Certification: Criteria and Checklist (TRAC) was the earliest published standard for trustworthy preservation system audit and certification, later revised as ISO 16363 and published in 2012. The Center for Research Libraries (CRL) established an Audit and Certification Committee that, between 2010 and 2015, conducted audit and certification for six digital preservation systems in the US and Canada, including Portico and CLOCKSS, according to TRAC, affirming their trustworthiness while identifying areas for improvement in organizational management, preservation object handling, and infrastructure. TRAC' s applicability has been validated through certification practice.

In 2010, Europe's CCSDS/ISO Repository Audit and Certification (RAC) Working Group, Data Seal of Approval (DSA), and DIN Working Group' s "Trustworthy Archives–Certification" signed a memorandum to create a European framework for digital preservation audit and certification, proposing a three-level certification framework: basic certification based on DSA standards to obtain DSA certification marks; extended certification based on ISO 16363 for self-audit certification; and formal certification based on ISO 16363 for complete external audit certification. DSA has established a complete certification mechanism and standardized procedures, with 65 European institutions' digital preservation systems, including the German National Library and the Dutch National Library, having obtained DSA certification by the end of October 2016. The

EU Seventh Framework Programme-supported APARSEN (Alliance Permanent Access to the Records of Science in Europe Network) developed corresponding specifications for ISO 16363-based extended and formal certification to guide certification trials within the APARSEN alliance.

China' s National Digital Science and Technology Literature Resources Long-Term Preservation System Demonstration Project, referencing relevant international standards (ISO 16363) and practices, formulated trial versions of the Trustworthy Preservation System Self-Assessment Manual and Long-Term Preservation Trustworthiness Certification Specification, and conducted self-audits and external certification of the preservation system at the National Science Library, Chinese Academy of Sciences as a compliant preservation institution, preliminarily confirming the system' s trustworthiness and laying a foundation for improving trustworthy certification mechanisms for digital resource preservation. As digital information resources requiring long-term preservation increase and become more complex, collaborative preservation networks and their trustworthy certification have become pressing issues.

3 Economic Support Models for Long-Term Preservation of Digital Publications

Long-term preservation of digital publications involves substantial and sustained economic and management investment, requiring long-term and adequate economic support. Economic support needs vary across different preservation service models and corresponding cost burden mechanisms. Scientifically assessing the costs and benefits of digital preservation and rationally arranging support funding and burden mechanisms are key concerns for all stakeholders. European and American institutions and organizations implementing digital preservation have conducted research on preservation costs for different models.

3.1 Research on Cost and Estimation Models

Over the past decade, projects including Germany' s DP4lib (Digital Preservation for Libraries), the UK's LIFE Tool (Life Cycle Information for E-Literature) by University College London and the British Library, Denmark' s CMDP (Cost Model for Digital Preservation) by the Royal Danish Library and Danish National Archives, the Netherlands'DANS Cost Model, and the APARSEN alliance have conducted research on cost analysis and modeling from perspectives such as digital object processing, procedures, cloud storage, and third-party services. APARSEN' s report *Report on Cost Parameters for Digital Repositories* analyzes cost models published by relevant research projects, comparing their cost parameters with ISO 16363 certification indicators, while its report *Report on Testing of Cost Models and Further Analysis of Cost Parameters* presents test results of digital preservation service cost models and evaluates their cost-benefit relationships.

The 4C (Collaboration to Clarify the Cost of Curation) project, involving 13

organizations from seven European countries, compiled ten cost models for reference and potential adoption by digital preservation institutions, as shown in Table 2 . Each model includes descriptions of its purpose, applicable information assets (such as formatted text, unformatted text, hypertext, graphics, databases, etc.), targeted preservation activities (such as ingest, preservation, management, etc.), preservation conditions (such as storage equipment, migration equipment, human resources, etc.), preservation duration, cost variables (such as source format, target format, annual preservation volume, salary levels, human input, etc.), and corresponding analysis and evaluation tools along with instructions and links for obtaining them. The 4C project' s report *From Costs to Business Models* explores how to design and develop business models for long-term preservation based on cost analysis, providing OAIS reference model-based business model templates and related toolkits.

3.2 Economic Support Models for Preservation Systems

(1) Portico, a non-profit third-party preservation service for digital publications managed by ITHAKA, preserves 26,163 electronic journals, 752,694 e-books, and works with 409 publishers and 971 libraries in 21 countries (42% US libraries) as of October 2016. Portico' s operating funds primarily come from publishers and libraries that benefit from its preservation services. Libraries pay annual preservation service fees ranging from $1,545 to $24,720 based on their annual procurement budgets, while publishers pay fees ranging from $250 to $81,960 based on their digital publication sales. Portico also receives funding from charitable organizations, foundations, and government agencies.

(2) CLOCKSS, organized by Stanford University Libraries with support from the US National Science Foundation and Mellon Foundation, is a distributed joint preservation system for digital publications with preservation nodes at 12 libraries in North America, Europe, and Asia, partnering with 283 libraries and 212 publishers as of October 2016. CLOCKSS operating funds come from participating libraries and publishers as beneficiaries, with libraries paying annual fees from $455 to $15,150 based on procurement budgets and publishers paying from $227 to $26,765 based on journal sales.

(3) National-Level Preservation Systems. The British Library, German National Library, and Dutch National Library bear national responsibility for long-term preservation of digital publications, primarily using legal deposit models for domestically published materials with system construction and operation funded entirely by government budgets. These institutions have established digital preservation policies and development plans with different characteristics. The British Library prioritizes preservation sustainability in its strategic planning, the German National Library participates in developing trustworthy certification standards while exploring preservation services and cost analysis for institutions with preservation needs, and the Dutch National Library plans to develop sustainable business models while encouraging public and private responsibility for preserving digital academic and cultural heritage.

The UN' s *Transforming Our World: The 2030 Agenda for Sustainable Development* includes strengthening protection of world cultural and natural heritage as a goal, and the IFLA Strategic Plan 2016-2021 calls for incorporating this UN goal into national laws and development plans. Digital scientific and technical literature resources constitute fundamental support for China' s innovation-driven development strategy, and their long-term preservation must be reliable and sustainable.

This paper proposes the following recommendations:

(1) **Advance strategic planning and policy development**. Long-term preservation of digital scientific and technical literature concerns broad and long-term national and public interests, representing public infrastructure and services requiring national leadership, coordination, and long-term support. Preservation should be incorporated into national scientific and technological development plans as part of scientific infrastructure. The national will for long-term preservation of digital publications in China should be established, clarifying statutory rights of public libraries to preserve digital publications and requiring institutions using public funds to purchase international digital publications to ensure resources are preserved domestically. Domestic digital publication providers should guarantee reliable long-term preservation through legal deposit or participation in national preservation systems.

(2) **Establish reliable economic investment mechanisms**. Through national special projects and the national scientific and technical literature resource guarantee platform, ensure concentrated investment for system construction and, more importantly, stable funding support for stable operation and continuous upgrading of preservation systems, including robust operation and maintenance, preservation capacity expansion with growing resources, system hardware and software upgrades, continuous tracking of important preservation technologies and policies, regular public audit and certification, high-level research and operations team training, and public awareness education. Simultaneously, explore cost-sharing mechanisms under cooperative preservation models and reasonable investment mechanisms applicable to multiple preservation models.

(3) **Strengthen technical and management standardization**. Standardized and reliable technology, processes, and management constitute the fundamental basis for preservation sustainability. This requires establishing and improving technical, process, and management standards for preservation systems, promoting their implementation and verification, continuously tracking developments in relevant technologies, methods, and mechanisms, and ensuring scientifically sound process organization and management mechanisms to guarantee operability, describability, manageability, and verifiability of preservation processes.

(4) **Emphasize trustworthy audit and certification mechanisms**.

Open, standardized, and continuous trustworthy preservation system auditing and certification effectively promote standardized construction, operation, and management, alleviate publisher concerns, secure public support, demonstrate funding effectiveness, and form the basis for international and cross-domain preservation cooperation. Trustworthiness auditing and certification must follow internationally recognized standards and best practices for reliable public services, while developing certification capabilities according to requirements for organizations providing trustworthy auditing and certification (such as ISO 16919).

(5) **Build a long-term preservation knowledge and capability community**. Over the past decade, global research and practice in digital preservation have gradually formed a corresponding knowledge system encompassing various specialized technologies, standards, and specifications, requiring numerous specialized personnel and improved awareness and participation capabilities among decision-makers, management, scientific communities, educational institutions, and the public. Research is needed on emerging challenges such as rights, technologies, costs, implementation, and management mechanisms for preserving new types of rich-media or social-media digital knowledge content, along with strengthened cross-domain and international exchange and cooperation to fully share research results. These needs call for enhanced construction of a long-term preservation knowledge and capability community.

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Author Contributions

Zhang Xiaolin: Conceived research ideas, designed research framework and paper structure, revised paper;
Zheng Jiancheng: Designed paper structure, reviewed and analyzed sustainability framework content, wrote paper;
Zhao Yan: Discussed paper structure, reviewed and analyzed preservation management sustainability materials;
Wu Zhenxin: Discussed paper content, reviewed and analyzed technical and security standard materials;
Yin Gaolei: Reviewed and analyzed trustworthiness certification materials;
Xiao Man: Translated and analyzed economic sustainability materials;
Chen Xiujuan: Translated and analyzed economic support model materials.

Conflict of Interest Statement

All authors declare no conflict of interest.

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Study of Sustainable Support Mechanisms for Long Term Preservation of Digital Publications

Zheng Jiancheng[1] Zhang Xiaolin[1] Zhao Yan[1,2] Wu Zhenxin[1] Yin Gaolei[1,2] Xiao Man[1] Chen Xiujuan[1,2]

[1](National Science Library, Chinese Academy of Sciences, Beijing 100190, China)
[2](University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract: [Objective] This paper aims to analyze the challenges for long term preservation of digital publications, and to promote the development of sustainable support mechanisms. [Methods] Based on a systematic literature analysis, the paper focuses on developing a framework of sustainability issues and tools. Building on previous analysis, it presents the trustworthy auditing and certification needs, standards, and processes, and summarizes cost models and investment models for digital preservation. [Results] This paper puts forth some specific suggestions concerning sustainable support mechanisms for long term preservation of digital publications. [Limitations] Only provide a brief overview of economic support models and related research. [Conclusions] The long term sustainability includes format sustainability, system sustainability, and service

sustainability for digital preservation, and it covers the concepts of managerial, financial, and political sustainability in the domain of service sustainability. The paper provides a few recommendations for developing sustainable support mechanisms for digital preservation.

Keywords: Digital publications; Long-term preservation; Sustainability; Support mechanism

Note: Figure translations are in progress. See original paper for figures.