Technical and Management Issues in Library RFID Implementation (Post-print)

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Abstract

[Purpose/Significance] To expound on the current application status of RFID technology in libraries in China, providing reference for libraries that employ RFID technology. [Method/Process] By combining on-site experience, interviews, industry expertise, and existing research, this study summarizes and analyzes the technical and managerial issues encountered during the introduction and implementation of RFID technology in Chinese libraries. [Result/Conclusion] RFID technology is merely a tool; resource development and service innovation constitute the essence of library development. For the vast majority of libraries, fully exploiting the potential of existing technologies represents a better choice than introducing innovative technologies.

Full Text

Preamble

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Technical and Management Problems of Implementing RFID in Libraries

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Abstract: *[Purpose/Significance]* This paper outlines the current application status of RFID technology in Chinese libraries to provide reference for libraries considering RFID adoption. *[Method/Process]* Based on site visits, interviews,

industry experience, and existing research, this study summarizes and analyzes the technical and management problems encountered during RFID implementation in Chinese libraries. *[Result/Conclusion]* RFID technology is merely a tool; resource development and service innovation constitute the essence of library development. For most libraries, fully exploiting existing technologies represents a better choice than introducing innovative technologies.

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With the continuous maturation of Radio Frequency Identification (RFID) technology and substantial reductions in tag prices, RFID applications in libraries have spread like wildfire, particularly the self-service model built upon this technology, which has been warmly embraced by libraries. However, amid this favorable market trend, many libraries maintain a "cautious wait-and-see" attitude and have not rushed to adopt the technology. To understand the real situation of RFID application in libraries, the authors visited representative libraries in Beijing, Shanghai, Guangdong, and other regions, consulting with staff where possible. Combining site experiences, interviews, industry practices, and existing research, this paper analyzes and summarizes the technical and management problems in implementing RFID technology in Chinese libraries.

1. International and Domestic Research Status and Domestic Application of RFID

1.1 International Research Status

Through searches of the OCLC WorldCat monograph catalog and the Web of Science Core Collection (SSCI) database, we identified 14 monographs and 238 articles on RFID. Analysis reveals these works primarily introduce library RFID background, system composition, whether to adopt RFID technology, supplier selection, and privacy and security issues. The literature mainly focuses on case studies and experiences, implementation guidelines, and return on investment.

1.2 Domestic Research Status

China has published three relevant monographs. Content-wise, these books focus on technical analysis, scenario analysis, and case studies; or they emphasize university library cases to provide references for RFID adoption; or they conduct research from technical and standards perspectives. These works further improve RFID system application and management specifications in libraries, providing theoretical support for broader RFID promotion.

In terms of journal articles, Chinese scholars have published numerous papers. Representative works can be categorized into four research themes: First, introductory articles predominate, representing exploratory research, such as China' s first published paper in 2004, "Wireless Technology for Library Services–RFID

Applications." Second, building on initial exploratory research, scholars began examining specific issues like implementation costs, return on investment, standards, and privacy. Third, status summaries and experience reviews comprehensively capture the actual development of RFID in Chinese libraries, summarizing valuable lessons from practice to inform future research. Fourth, studies explore RFID application scenarios and predictions in smart libraries, such as building sensor networks based on RFID to provide technical support for smart libraries.

In summary, although existing research is abundant and covers broad themes, it tends to be either macroscopic and abstract or focused on specific applications or technical details. Few studies systematically summarize the technical and management issues of greatest concern to libraries from the perspective of engineering practice and the library community.

1.3 Current Status of RFID Adoption in Chinese Libraries

In February 2006, the Cheng Yi College Library of Xiamen Jimei University (hereinafter "Cheng Yi College Library") opened its comprehensive collection to the public, becoming China' s first university library to apply RFID collection management systems and marking the formal beginning of RFID practice in Chinese libraries. In July of the same year, Shenzhen Library—the first library in China to comprehensively adopt RFID technology—officially opened to the public. Shenzhen Library' s successful operation prompted more libraries to consider RFID adoption. In May 2007, Wuhan Library, the first library in China to adopt "domestically-produced" RFID equipment, officially opened, representing another breakthrough in domestic RFID application and signaling that Chinese library RFID technology had basically matured.

By the end of 2011, 127 libraries in mainland China (including Cheng Yi College Library of Xiamen Jimei University, Shenzhen Library, Xiamen Children' s Library, Shanghai Changning District Library, Shantou University Library, Wuhan Library, National Library of China, Hangzhou Library, Deng Xiaoping Library, Tianjin Library, Sanya Library, and Guangzhou Library) had completed RFID system deployment. By 2015, 342 libraries nationwide had applied RFID systems, including 243 public libraries, with 72.38% using high-frequency RFID. Compared with the total number of libraries nationwide, this still represents a small portion, concentrated primarily in economically developed regions such as Beijing-Tianjin-Shanghai, the Yangtze River Delta, and the Pearl River Delta.

According to a market analysis report released by Zhiyan Consulting, China' s library RFID market size was 493 million yuan in 2017, growing to 937 million yuan in 2018, demonstrating rapid development. As technology costs continue to decline, more libraries will adopt RFID technology. According to innovation diffusion theory, libraries that have adopted RFID technology remain early innovators and early adopters; the majority of libraries are still cautiously considering adoption, and the era of mass adoption remains distant.

2. Technical Problems in Library RFID Implementation

RFID technology application in libraries is undoubtedly successful overall. However, due to the complexity and particularity of library application scenarios, certain technical problems remain difficult to resolve effectively, preventing RFID equipment from achieving ideal performance. Currently, RFID equipment used in libraries mainly includes self-service borrowing/return machines, 24-hour self-service return machines, 24-hour self-service libraries, RFID security gates, mobile inventory carts, smart bookshelves, automatic book sorting systems, and intelligent three-dimensional book storage. This section examines potential technical problems with each device.

2.1 Technical Problems with Self-Service Machines

Self-service borrowing/return machines are essentially computers integrated with RFID readers, and their technical problems primarily stem from RFID reader performance.

(1) Indoor self-service machines. Different equipment manufacturers produce self-service machines with varying induction ray patterns—some completely vertical, others dispersed (as shown in Figure 1 [Figure 1: see original paper] left)—which primarily affect book reading effectiveness. On one hand, insufficient induction range causes missed reads. Librarians report that when multiple books are stacked on the induction area, overlapping tag positions or excessive stacking height beyond the induction range can result in missed reads. Since patrons rarely pay attention to on-screen feedback, books may not be recorded in the system. To prevent this, most libraries post friendly reminders such as "Please process books one at a time."

On the other hand, excessive induction range causes misreads. When books are placed near the induction area or within close range, the machine may read their tags, or even tags from books in return bins, incorrectly charging books to patron accounts. Consequently, some libraries install physical barriers beside the induction area or confine induction rays within a rectangular cubic space, largely preventing misreading phenomena.

(2) Outdoor 24-hour self-service return machines. These wall-mounted machines only offer return functionality, allowing patrons to return books regardless of library operating hours. Unlike indoor machines, they require single-book processing. Most display prominent reminders: "Return one book at a time," primarily to prevent patrons from mistakenly feeding non-tagged items or multiple items simultaneously into the return slot, which would cause the machine to "swallow" untagged materials.

Some return slot heights are insufficient for thick books. Additionally, some lack human sensors, creating safety hazards, particularly in children's libraries where such devices are crucial. Many libraries report high usage rates for self-service return machines after hours but low usage during operating hours for two reasons:

First, these machines cannot effectively handle CDs or videotapes, prompting reminders to "Please return CDs or videotapes at staff workstations." Second, even single-book returns sometimes fail to read effectively, leading patrons to prefer counter service over time.

2.2 Technical Problems with 24-Hour Self-Service Libraries

In December 2007, China' s first 24-hour self-service library appeared outside Dongguan Library' s south gate. These systems primarily consist of automatic book retrieval systems and self-service borrowing/return machines, supplemented by self-service card issuance systems, requiring stable network environments and typically located in communities away from library buildings. Automatic retrieval systems employ either "robotic arm" or "turntable" principles. Robotic arms have limitations, as cleanliness and temperature affect operation. According to Yichang Library staff, robotic arms frequently jam, leaving self-service libraries in constant disrepair.

The self-service machines in these libraries share problems with those discussed above, but with additional complications: being outdoors and remote, they typically connect via wireless networks. When wireless networks fail, the machines become paralyzed, and patrons, unable to diagnose the cause, assume equipment malfunction. A 2017 report noted that a self-service library in Wuzhou frequently experienced network connection or system failures that were not promptly resolved. A September 2013 report indicated that multiple self-service libraries in a Beijing community suffered from malfunctioning query machines and buttons. Similarly, self-service card issuance and patron login systems require stable networks; once disconnected, these functions become unavailable.

2.3 Technical Problems with RFID Security Gates

Beyond book identification, RFID tags detect collection status. RFID security gates read tag status information as books pass through; books marked "checked out" pass freely, while others trigger alarms. Proper operation requires tags not be shielded by objects and that checked-out books avoid tag overlap, otherwise false negatives occur. Another issue arises because high-frequency RFID tags have relatively large surface areas, making them vulnerable to damage during circulation and enabling removal by patrons lacking public consciousness, allowing books to pass through security gates unchecked.

Additionally, some clothing stores use high-frequency RFID tags' AFI or EAS security bits for theft prevention. However, standards for RFID tag content storage vary across industries, with similar definitions for EAS security bit codes (libraries use AFI data standard: 0x07 for "in library," 0xC2 for "checked out"), causing false alarms when patrons wearing new clothing pass library security gates. Libraries can address such issues through public education or enhanced security patrols. For overly conspicuous tags, some libraries print their logos on tags for concealment and promotion.

2.4 Technical Problems with Mobile Inventory Carts

At the University of Electronic Science and Technology of China' s dense stacks (using ultra-high frequency RFID tags), staff scan books individually rather than scanning multiple books from a distance, then manually verify scan counts against system displays. In this scenario, RFID inventory equipment merely functions as rapid data entry, with efficiency far below theoretical levels.

Staff report that even single-book scanning misreads books on other shelves and misses books on the target shelf. Two main causes exist: First, high shelf density and narrow inter-shelf spacing, combined with high-sensitivity, wide-range UHF RFID readers, easily cause misreads. Although many libraries reduce reader power to narrow reading range, this cannot fundamentally solve the problem technologically. Second, damaged or overlapping RFID tags create electromagnetic shielding, preventing individual tags from being identified, requiring staff to manually verify and identify books with unreadable tags for replacement or repositioning. In summary, high-frequency RFID tags suffer from short reading distances, overlapping shielding, and damage causing missed reads; UHF RFID tags have long reading distances prone to misreading, poor anti-interference, and human body shielding also causing missed reads.

Strictly speaking, China has not yet effectively solved the problem of rapid non-contact long-distance reading of multiple books, with efficiency falling short of expectations. However, libraries can collaborate with enterprises to strengthen RFID application research, such as Singapore libraries' development and deployment of robotic librarians for inventory work, seeking feasible solutions to effectively reduce labor consumption and improve service efficiency.

2.5 Technical Problems with Smart Bookshelves

Smart bookshelves have generated extensive discussion in the library community. Manufacturers claim they "can monitor and inventory collections, enable book location queries, and miscataloging statistics," suggesting smart bookshelves eliminate manual inventory. In reality, this is not the case for two main reasons: First, current hardware processing speeds cannot upload book information and update database status in real time, causing information lag and resulting in "system shows available but book is missing" or vice versa, preventing accurate feedback on borrowing intentions. Second, excessive book density on smart shelves causes tag overlap or physical obstruction, leading to misreading and affecting database accuracy. Additionally, smart bookshelves are expensive to build; even Guangzhou Library and Huangpu District Library have only implemented small-scale pilots.

Given information collection and synchronization lags, smart bookshelves are generally limited to new arrivals and special collections. Furthermore, comprehensive smart bookshelf adoption would reduce libraries to computerized information retrieval services, depriving patrons of the experience of browsing physical collections and facing them with cold machines and disordered ware-

houses, not to mention extreme scenarios like power outages or system crashes. In short, current smart bookshelf technology remains in trial stages with many areas needing improvement.

2.6 Technical Problems with Automatic Book Sorting Systems

Currently applicable technologies include transfer-type, cross-belt, sliding-shoe, and AGV robot sorting systems. These systems can identify and sort RFID-tagged circulating materials by category, achieving fully automatic collection, classification, and organization, typically integrated with RFID 24-hour self-service return machines and conveyor systems to quickly and accurately complete sorting and reduce staff workload. This section discusses the most widely used transfer-type system and the newer AGV system.

(1) Transfer-type sorting system problems. Using Guangzhou Children' s Library as an example, besides classification difficulties and component wear, these systems frequently experience transmission problems requiring manual intervention. The system processes books twice—after initial self-service return, books undergo a second return operation to account for mechanical transmission uncertainties. This affects efficiency; despite double processing, some books remain unidentifiable and enter an "unknown" bin for manual sorting. Component wear is severe due to continuous operation, with mechanical wheels and belts degrading and causing jamming. The system requires specific book spacing, necessitating manual position adjustment before sorting. Special-sized books cannot be transmitted smoothly, causing jams.

(2) AGV robot sorting system problems. In July 2019, China' s first AGV robot sorting system launched at Bao' an District Library. Under computer system control, AGV carts follow predetermined routes to deposit books into corresponding slots based on RFID tag information. AGV systems offer high processing efficiency and significantly reduce staff workload, but AGV carts feature complex structures with mostly imported components, making them expensive with ongoing maintenance costs for batteries and magnetic/optical sensors—difficult for small and medium libraries to afford. Additionally, on-site observations suggest AGV carts may damage books to some extent.

2.7 RFID Tag Damage and Aging

Long-term use makes RFID tag damage and normal aging non-negligible issues. High-frequency RFID tags are relatively thin, with internal coils easily broken by folding or compression, rendering tags inoperable without induction current. UHF RFID tags are slender, attachable to book spines, more concealed, and less prone to damage, thus offering longer lifespans. Regardless of frequency or attachment location (page interior, back cover, or spine), tags experience damage or aging requiring replacement.

The authors visited Guangzhou Children' s Library, Shenzhen Bao' an District Library, and Suzhou Second Library. Guangzhou Children' s Library uses

transfer-type sorting systems. Interestingly, librarians report that rarely borrowed books require more frequent tag replacement than heavily used books, which have more reliable lifespans.

3. Management Problems in Library RFID Implementation

The adage "three parts technology, seven parts management" often applies. While technical problems may be difficult to resolve immediately, rational decision-making and effective management can prevent issues or address those temporarily unsolvable technologically.

3.1 Timing of RFID Introduction

Interviews revealed some libraries introduce RFID systems when financially capable, seizing opportunities presented by new construction or renovation/expansion projects. Others adopt RFID when facing staff shortages, dramatically increasing service volumes, and urgently needing service quality improvements.

Former Shenzhen Library Director Wu Xi once stated: "…establishing a 'technology-based library' policy was not proposed by prescient visionaries but resulted from historical limitations—a forced choice." Shenzhen Library's initial RFID adoption was an "unavoidable" decision, requiring risk-taking as a pioneer. Later adopters typically observed implementation effects before seizing construction/renovation opportunities. Some RFID equipment requires special spatial configurations, such as automatic sorting systems. Guangdong Provincial Sun Yat-sen Library did not install automatic sorting due to unsuitable building space and difficult renovation. Guangzhou Library capitalized on new building construction to install China's most advanced automatic sorting system, making its RFID system the nation's largest. Thus, new construction or renovation provides crucial opportunities for seamlessly integrating RFID systems to improve service efficiency.

As public libraries' social status and functions rise, citizen enthusiasm for library use increases, exacerbating staff shortages and making RFID systems the preferred solution. For example, after Guangzhou Library's new building opened in June 2013, circulating materials and patron visits grew annually—impossible to manage without RFID. For university libraries, RFID systems enhance service efficiency, freeing staff for knowledge-intensive services like subject librarianship. Shanghai Jiao Tong Library, with its new building completed in 2008, did not 大规模 introduce RFID until 2014. The library suggested to vendors that self-service machines include "recommendation" functions based on patron reading records and data analysis. Thus, improving service quality and levels amid staff shortages represents the primary driver and urgent task for RFID adoption. Sun Yat-sen University Library initially introduced RFID to support its development strategy, enabling more staff to engage in subject services supporting

the university' s "double first-class" construction.

3.2 RFID System Selection

RFID systems broadly divide into high-frequency (HF) and ultra-high frequency (UHF) systems, presenting libraries with a binary choice involving development planning. Generally, UHF offers stronger signals and better functional expansion but more technical problems. HF, with weaker signals, is more technologically mature but less conducive to functional expansion. In 2006, Shantou University Library introduced UHF RFID for circulation, shelf-reading, and inventory, achieving full UHF RFID self-service by 2011—the first Chinese university library to adopt UHF RFID. The authors' survey found university libraries almost universally choose UHF RFID, while public libraries tend toward HF RFID, though some public libraries also adopt UHF.

From University of Electronic Science and Technology Library: "UHF RFID was chosen primarily because tags are cheaper than HF tags, and more importantly, better concealed. University students are highly curious; conspicuous HF tags would be easily damaged. Even well-concealed UHF tags are frequently removed by students."Shanghai Jiao Tong Library similarly chose UHF for being cheaper, more sensitive, more convenient, and more functionally expandable than HF. Thus, university libraries prioritize functionality and tag cost.

Public libraries' RFID selection appears based on local "radiation effects" or regional sharing. In Guangdong, Shenzhen Library pioneered HF RFID adoption without domestic standards for reference, making it an important model for regional public libraries. Consequently, all Guangdong public libraries adopted HF RFID systems to achieve regional standardization, laying foundations for building "library cities," interlibrary loan, and resource optimization. Bao' an District Library initially chose UHF but later switched to HF to align with Shenzhen Library' s system and the municipal culture bureau' s "library city" vision, wasting substantial resources.

3.3 RFID Tag Maintenance

UHF RFID tags generally attach to book spines, causing some damage during replacement. HF RFID tags typically attach to the last page or inside back cover, causing less damage due to thicker, smoother cover materials. Librarians report that ironically, rarely borrowed books require more frequent tag replacement than heavily used books.

Thus, RFID tags are not optimal for book preservation, especially UHF tags. Libraries should carefully consider this, particularly for ancient books, which should not simply use RFID tags but alternative solutions like covers with embedded RFID tags.

3.4 RFID Hardware System After-Sales Service

After-sales service for library RFID systems is a neglected issue. At Guangdong Provincial Sun Yat-sen Library, a "Temporarily Out of Service" sign on a 24-hour self-service return machine explained: (1) quality issues—degraded conveyor belts after long-term operation no longer remain taut, potentially damaging books; (2) delayed after-sales service preventing timely on-site repairs. Across visited public and university libraries, staff consistently reported delayed after-sales service or poor product quality. Currently, vendors focus entirely on market promotion while neglecting after-sales support, forcing libraries to resolve RFID system issues independently. Libraries lacking such technical capabilities inevitably suffer service quality impacts, even at the National Library of China where all self-service machines malfunctioned simultaneously, forcing patrons to queue at staff workstations and causing severe congestion and efficiency drops. High staff turnover exacerbates the problem, as new staff require extensive time to familiarize themselves with RFID systems before working effectively, further reducing after-sales efficiency.

As RFID hardware systems are emerging technologies less stable than mature computer hardware, libraries should carefully consider after-sales support when selecting systems to avoid unnecessary losses and negative impacts.

3.5 Strengthening Operational Management to Compensate for RFID Technical Defects

Self-service return machines cannot distinguish whether stacked books equal tag counts; UHF RFID tags' excessive effective reading distance causes misreading; HF RFID tags' large surface area causes overlapping shielding and exposure. These technical defects stem from mechanical design flaws, technical principles, or current technological limitations. Despite these challenges, libraries must overcome difficulties through strengthened operational management to ensure normal RFID system operation.

"Return one book at a time" currently represents the best method to prevent machines from swallowing untagged items or multiple books. The "one-meter line" creates distance, preventing books from being incorrectly charged to other patrons. Printing library logos on HF tags within a certain range on back covers reduces overlapping shielding and provides concealment. While not perfect solutions, these measures prove effective. Additionally, libraries must regularly conduct education campaigns to improve patron quality and public consciousness.

As Peking University Library Director Zhu Qiang stated, whether more advanced library-suitable technologies will emerge before RFID matures remains unknown. Therefore, libraries require more consideration when adopting RFID. For libraries, RFID is merely a tool, while resource development and service innovation represent their essential connotation. As non-profit institutions, libraries must make technology investments cautiously. Perhaps they should

focus more on fully exploiting existing technologies to improve service quality and management levels.

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Chen Dingquan: Proposed research ideas, methodology, and revised the paper.
Wang Mengzhuo: Conducted preliminary research and analyzed technical and management problems.
Qian Haigang: Analyzed technical and management problems, collected materials, and revised the paper.

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