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The relationship between medical equipment management outsourcing and performance

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THE RELATIONSHIP BETWEEN MEDICAL EQUIPMENT MANAGEMENT OUTSOURCING AND PERFORMANCE

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I hereby declare that this DBA dissertation is my original work
and it has been written by me in its entirety.
I have duly acknowledged all the sources of information
which have been used in this dissertation.

This DBA dissertation has also not been submitted for any degree
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Abstract

Medical equipment, as a core component of a hospital's fixed assets, provides essential support and assurance for the hospital to deliver medical services and enhance competitiveness. The operation of public hospitals in China is a top priority for deepening medical reforms. As hospitals transition from focusing on revenue to centering on costs, comprehensive management of medical equipment becomes a critical aspect of hospital operation management. In the scenario of utilizing the management service outsourcing mode for comprehensive management of medical equipment, equipment performance naturally becomes a topic of special interest in the industry.

Given this, this study aims to investigate how the full life cycle management mode of medical equipment influences equipment performance in Chinese public hospitals that employ medical equipment management outsourcing. These goals entail: (1) Expanding the theory on the connection between medical equipment management outsourcing and performance; (2) Enhancing the critical aspects of medical equipment full life cycle management and constructing a methodical model for the relationship between medical equipment management outsourcing (full life cycle management) and performance; (3) Validating the influence of medical equipment management outsourcing on performance through the difference-in-differences (DID) model; (4) Utilizing the questionnaire survey to confirm the impact of medical equipment's full life cycle management on performance within the outsourcing mode, and investigating how different medical equipment categories affect medical equipment management outsourcing and performance.

Empirical Research 1 indicates a positive correlation of medical equipment management outsourcing (full life cycle management) with both financial and non-financial performance. Empirical Research 2 reveals that within the outsourcing mode, medical equipment management outsourcing correlates positively with financial performance, non-financial performance, and performance. Additionally, the medical equipment category exerts a positive impact on management outsourcing and financial performance, as well as performance; however, it does not have any effect on management outsourcing and non-financial performance.

This study indicates that Chinese public hospitals implementing medical equipment management outsourcing and full life cycle management can notably boost equipment utilization rates, enhance clinical satisfaction, and improve equipment performance. Concentrating on high-risk and large-scale equipment can enhance the financial performance of equipment while ensuring the safe and effective operation of all equipments can provide crucial support for core diagnosis and treatment services. The research has explored an interdisciplinary research methodology, enriched the theory of outsourcing in professional specialization, and establishing a medical equipment management system with Chinese characteristics.

Due to limitations in my academic expertise and objective conditions, this study still has many constraints and shortcomings, which require further exploration in the future.

Keywords: medical equipment management outsourcing, medical equipment full life cycle management, performance

Contents

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Chapter I Introduction

This chapter begins by outlining the research background of the dissertation, proposing the research questions, and elucidating the research significance and main innovative points, and concludes by introducing the structure and chapter arrangement of the dissertation.

1.1 Research Background

China possesses a large population, faces a severe aging demographic, and experiences a rapidly growing demand for medical services. Concurrently, issues like inadequate distribution, unequal allocation, and inefficient operations of medical resources are becoming increasingly pronounced. Public hospitals serve as the core of China's health service system. What strategies can be implemented to enhance the high-quality development of public hospital operations? How can the allocation of social medical resources be optimized effectively? Constant exploration and innovation are required.

Medical equipment refers to the instruments, devices, appliances, and materials (including software) used for the human body alone or in combination. It constitutes a vital component of hospitals' fixed assets, delivering support and assurance for high-quality medical services. At present, many public hospitals continue to expand or update their medical equipment, but they fail to establish corresponding management information systems, improve the operation and management system, and address the severe shortage of professionals. Medical equipment management outsourcing, as an innovative management mode, has attracted the attention of both the industry and academia.

Medical equipment management is an important part of modern hospital management, combining the universal principles of comprehensive equipment

management with the distinct characteristics of the medical industry. Medical equipment management outsourcing blends the interdisciplinary aspects of "management, engineering, medicine, and information," exhibiting commonalities with outsourcing practices while also possessing specific characteristics of public service outsourcing.

1. "Management"

(1) Asset attribute: Most medical institutions in Europe and the U.S. are private non-profit hospitals, with a relatively high degree of privatization in medical equipment assets. In Chinese public hospitals, medical equipment constitutes more than 50%-80% of fixed assets. These funds mainly originate from financial appropriations and self-raised funds. Spare parts for medical equipment, are also considered state-owned assets. All these are subject to the management principle of "unified leadership, centralized management, graded responsibilities, and accountability system."

Public hospitals should reorient towards their primary mission of public welfare, maximizing the utility of medical equipment assets while considering both social and economic benefits. As a result, it is imperative to implement scientific, refined, and standardized management practices.

(2) Development stage: Take the U.S. as an example. New medical equipment in its hospitals has been relatively stable, mostly undergoing equipment renewal and software upgrading. In the full life cycle of the equipment, procurement costs typically make up around 20%, with operation and maintenance costs in subsequent phases accounting for approximately 80%. Therefore, European and American hospitals highly prioritize full life cycle management of the equipment, especially emphasizing cost budgeting and

control during the later stages. However, the medical equipment market in China is currently experiencing ongoing expansion. Numerous hospitals possess equipment in the early phases of their life cycles, characterized by low failure rates and a relatively high proportion of procurement costs. Regrettably, many hospitals tend to overlook the subsequent management and maintenance of this equipment.

(3) Law and regulation system: In Europe, the U.S., and some other countries, the supply chain for medical equipment spare parts is highly open. Medical equipment refurbishment and the use of second-hand equipment spare parts are permissible as long as they comply with industry quality and regulatory standards. In the current Chinese market, whether it is medical equipment or spare parts included in medical device management, whether it is refurbished or second-hand, laws, regulations, and policies do not currently permit their use. The *Regulation on the Supervision and Administration of Medical Devices* (2021) explicitly prohibits any medical device enterprise or user from operating or utilizing any medical device that is not legally registered or filed, lacks a conformity certificate, or has expired, been invalidated, or eliminated.

2. “Engineering”

(1) Discipline weakening: Medical engineering originates from and serves the clinical sector. It represents an emerging interdisciplinary field that has evolved, grown, and innovated in practice. At present, only a portion of large general hospitals value the medical engineering discipline and exert the important role of medical equipment management in their high-quality development. In most small and medium-sized hospitals, the medical engineering department tends to lose its significance, either through name

changes like the equipment department or apparatus department or by being placed under the general affairs department. In primary medical institutions, the lack of a dedicated medical engineering or equipment department, along with the absence of specialized equipment management personnel, results in basic medical equipment management existing in its original form—reactive maintenance or even negligence.

(2) Professional shortage: As per the data from the *2020 China Health Statistical Yearbook* (2021), professionals responsible for medical device repair fall under miscellaneous categories. In 2019, other health technicians constituted 8.11% in China. Notably, the statistical analysis did not specify medical engineering professionals separately, indicating a scarcity of such experts within the country's medical engineering discipline. In contrast to developed nations, where medical engineering professionals make up approximately 15-20% of health technicians, the presence of such professionals in public hospitals in China remains notably inadequate. Results from two investigations on medical engineers by Yu et al. (2004) reveal that within the talent structure of medical engineering in the surveyed hospitals, less than one-seventh possessed a bachelor's degree or higher degree, or held senior professional titles. Approximately one-third had an associate degree or intermediate professional designation, while around half had a secondary education background or junior professional title. The remaining consists mainly of logistics personnel or individuals without formal professional education or training.

(3) Outdated hardware setup: Over the past few years, biomedical engineering has advanced swiftly, introducing a plethora of integrated, modular,

and digital medical equipment that outpace traditional counterparts. For the medical engineering department, the original hardware facilities, mainly including testing equipment, maintenance equipment, and spare parts, can no longer keep up with the rapid development of the medical equipment industry. Except for some large public hospitals, most small and medium-sized medical institutions only have traditional testing and maintenance equipment, which are no longer adequate for the repair and upkeep of modern medical equipment. Likewise, concerning spare parts inventory, the majority of hospitals lack ample reserves, while basic medical institutions essentially lack spare parts warehouses.

3. “Medicine”

Drucker, a legend of management studies, considers hospitals “the most complex form of human organization.” Medical equipment integrates optical, electronic, physical, biochemical, radiation, information technologies, and more. It holds a critical position in disease prevention, diagnosis, treatment, scientific research, and education, significantly impacting the lives and health of individuals. Medical equipment is utilized in nearly all clinical departments, encompassing thousands of categories of materials and supporting dozens of diagnosis and treatment processes. The medical equipment management system must take into account factors such as cost, efficiency, quality, safety, compliance, and clinical satisfaction. The White Paper titled “Hospital-based Clinical Engineering Projects Must Aim at Quality and Safety” (David, 2014) emphatically highlighted that clinical medical equipment management, serving as a health technology management initiative, should prioritize crucial performance indicators such as quality, safety, and effectiveness.

4. “Information”

The full life cycle data of medical equipment asset management, operation and maintenance management, financial management, and other dimensions hold significant value for analyzing equipment performance, refining service procedures, and enhancing operational quality. However, information-based comprehensive medical equipment full life cycle management remains a significant weakness in the operational digital transformation of many public hospitals in China. All kinds of data are stored scattered, in different ways, and cannot be shared, resulting in a general phenomenon of an “information island.” For medical equipment management within major general hospitals, Internet of Things (IoT) technologies like RFID, APP, PDA, and 5G have not been extensively utilized. Additionally, many information-based platforms for medical equipment asset management lack integration with systems such as HIS, LIS, PACS, and WMS. Most small and medium-sized hospitals and primary medical institutions are still lacking medical equipment asset management software and applications.

To sum up, the study is conducted against an interdisciplinary, multi-dimensional, unique, and innovative backdrop. Interdisciplinary represents the emerging direction of future scientific advancements, with discipline integration being a crucial avenue for fostering breakthroughs in scientific and technological innovation. By leveraging China’s unique national circumstances, adhering to the evolving landscape of medical equipment management, and investigating methods to enhance equipment management performance, we hope to uncover a novel approach to unlock the potential of interdisciplinary collaboration.

1.2 Research Questions

The medical service reform is a worldwide challenge. The absorption of advanced management concepts and in-depth study of management paradigms are conducive to constructing a medical equipment management service mode with Chinese characteristics. Tracing back the research on comprehensive equipment management theory by predecessors, I find that since the 1960s and 1970s, based on system theory, information theory, and control theory, various industrially developed countries in the world have successively put forward representative theories on logistics, comprehensive equipment engineering, and total production management. U.K. researcher Parkes first mentioned the concept of comprehensive equipment engineering, aiming to minimize the full life cycle cost of equipment. This theory has been a milestone in the iterative development of equipment management modes. Building on the foundation laid by previous research, full life cycle management, central to comprehensive equipment management theory, is now progressively being integrated into medical equipment management.

When it comes to comprehensive medical equipment management, would it be more beneficial or detrimental for public hospitals in China to adopt comprehensive management outsourcing? Equipment performance is naturally a topic of great concern in the industry. After a review of the research on the relationship between outsourcing and performance, it is found that results may vary depending on the attributes of outsourcing business and key factors. In general, most studies confirm that an enterprise's non-core business outsourcing is positively correlated with performance. What findings can be obtained by applying outsourcing and performance research results to medical equipment

management? Most scholars believe that medical equipment management outsourcing can improve performance. However, Cruz and Rincon (2012) observed that research on operational services and service management appears to have neglected the medical engineering community, with scarce empirical research in this area. Some scholars also highlight disadvantages medical equipment management outsourcing may bring, such as equipment maintenance effect, spare parts quality, and response speed.

Studying the relationship between medical equipment management outsourcing and performance involves exploring the comprehensive issue of medical equipment allocation (hard power) and operational management (soft power). It is an interdisciplinary proposition that delves into the intersections of management, engineering, medicine, and information disciplines. This research holds profound significance for addressing the high-quality development of operations in Chinese public hospitals, optimizing the allocation of social medical resources, and addressing other challenging issues. This study, based on public hospitals in China, focuses on the outsourcing of comprehensive medical equipment management. By integrating the dual paths of integrated equipment management and performance, and outsourcing and performance, along with conducting thorough literature reviews and empirical research, this study endeavors to delve into two pivotal issues: the influence of medical equipment management outsourcing (including full life cycle management) on performance, and the regulatory function of medical equipment categories on medical equipment management outsourcing and performance.

1.3 Research Significance

This study aims to explore the relationship between medical equipment

management outsourcing and performance in Chinese public hospitals. From a "path-finding" to a "path-following" approach, it holds both theoretical and practical significance as outlined below.

1. Theoretical significance

(1) Drawing upon the theoretical frameworks of service outsourcing from mature specialized fields, applying them to the field of medical equipment management services, and evaluating the relationship between medical equipment management outsourcing and performance can help enrich the theoretical foundation of service outsourcing within industry segments.

(2) Within the context of deepening healthcare reforms in China's public hospitals, significant differences exist in organizational structure, management modes, and asset characteristics compared to Western medical institutions. Exploring the optimization of medical equipment management service modes and performance under diverse national contexts may yield varying conclusions, thereby improving the current theoretical foundation of medical equipment management research.

(3) Through the exploration of various empirical research methodologies, insights can be gained for the digital transformation of operations and interdisciplinary research in public hospitals, offering valuable guidance for future large-sample studies.

2. Practical significance

(1) Enterprises: Through the development of theoretical models and analysis of operational data in medical equipment management services, outsourcing projects can be consistently streamlined, leading to continuous enhancement of equipment performance. The research conclusions can also

offer a stronger basis for third-party enterprises to broaden their medical equipment management service business, initiate full life cycle fine management, and lead equipment housekeeper services.

(2) Hospitals: By exploring medical equipment management outsourcing, Chinese public hospitals can fundamentally transform the existing system, overcome professional talent constraints, establish a medical equipment information management system, and improve the medical equipment operation management system. “Professionals do professional work.” Exploring one-stop services for logistics such as medical equipment management is beneficial as it allows clinical doctors to focus on core diagnosis and treatment services, ensuring efficient collaboration in operations within the hospital.

(3) Society: Firstly, public hospitals have consistently formed the core of China’s healthcare service system. Advancing the reform of public hospitals stands out as the primary challenge in the new medical reform landscape. If the management outsourcing mode can overcome the existing management challenges related to logistics assets in public hospital equipment, it has the potential to partially resolve the issue. This could enhance the operational efficacy of state-owned assets and refine the distribution of social medical resources. Secondly, the distribution of medical resources in China exhibits an inverted triangle allocation pattern contrasted with a triangle of patient demand. Actively exploring medical equipment management outsourcing within the framework of medical communities and alliances holds practical significance for advancing hierarchical diagnosis and treatment systems, channeling high-quality medical resources to grassroots levels, and fostering the growth of telemedicine services. Moreover, the research also catalyzes the establishment

of a digital ecosystem platform for medical equipment management services. The collaborative sharing of equipment resources among different hospital campuses, hospitals, and regions will play a pivotal role in rectifying the uneven and insufficient distribution of medical resources. This approach will ensure comprehensive and full-cycle healthcare for the population, contributing to the realization of the Healthy China strategy.

1.4 Main Innovative Points

This study focuses on the medical equipment in Chinese public hospitals. It involves initial communication, proposal development, budget approval, business bidding, on-site services, and in-depth on-site investigation, to explore the impact of adopting a management service outsourcing mode and implementing full life cycle management on equipment performance. Reflecting on history to envision the future, this study introduces the following key innovative points when compared to previous relevant research:

1. Innovative point I

Building upon a foundation of core concepts and existing theoretical achievements, this study advances theoretical frameworks by integrating the dual paths of outsourcing and performance, and comprehensive equipment management and performance. It delves into the relational path between medical equipment management outsourcing and performance, and the potential positive impacts on equipment performance.

2. Innovative point II

By leveraging research on the correlation between service outsourcing and performance across diverse industries and amalgamating varied research findings from different angles, this study focuses on the application of

outsourcing theory within medical equipment management services. It leverages the theoretical model of service outsourcing in mature subdivisions, extracts key elements from the full life cycle management theory of medical equipment, combines measurable activities of clinical medical equipment management services, implants a research framework on the relationship between outsourcing and performance, demonstrates their positive correlation, and introduces medical equipment management risk categories as adjustment variables to evaluate their effect of regulation on medical equipment management outsourcing and performance.

3. Innovative point III

The study employs the DID model and questionnaire survey methodology to conduct an empirical analysis of the medical equipment performance in public hospitals. Utilizing both first-hand and second-hand data, as well as panel data and cross-sectional data, the paper demonstrates that in certain scenarios and contexts, integrating big data analytics with questionnaire surveys or expert interviews can pinpoint critical elements within a database, thereby offering a solid foundation for effective management decision-making.

1.5 Dissertation Structure

The dissertation consists of six chapters. The overall structure and content of each chapter are organized as follows:

Chapter I: Introduction. This chapter first introduces the research background, then puts forward the research questions, expounds on the theoretical significance and practical significance of this study, and provides the overall framework of the paper.

Chapter II: Literature Review. This chapter systematically reviews the

literature concerning the relationship between medical equipment management outsourcing and performance. Firstly, it outlines the definition of outsourcing and medical equipment management outsourcing, along with the theoretical basis and motivation of service outsourcing. Secondly, it examines and summarizes the theoretical literature on equipment comprehensive management and medical equipment full life cycle management. Thirdly, the literature regarding the definition, measurement, and influencing factors of outsourcing performance is revisited. Finally, the relationship between medical equipment management outsourcing and performance and that between medical equipment full life cycle management and performance are extensively reviewed.

The third chapter studies the hypothesis and theoretical model. This chapter combines classic theories and literature research from both domestic and international sources. Through theoretical deduction, research hypotheses are proposed, and a theoretical model is constructed to lay the foundation for empirical research in the following chapter.

Chapter IV: Research Design and Method. In this chapter, the research design is executed following the theoretical model. Initially, the research objectives, scope, and variables for measurement are identified. Subsequently, the empirical research subjects, data collection, and specific analytical methods are established based on the DID model and questionnaire survey method, respectively.

Chapter V: Result Discussion. This chapter analyzes and discusses the research hypothesis test results, primarily encompassing: Empirical Research 1, which involves descriptive statistical analysis, effect assessment of equipment utilization rate, effect assessment of clinical satisfaction, and robustness testing;

and Empirical Research 2, which includes descriptive statistical analysis, reliability test, validity test, correlation analysis, and regression analysis.

Chapter VI: Conclusion. This chapter focuses on summarizing the research conclusions, summing up insights and recommendations, outlining the limitations of this study, and providing prospects for future research.

Chapter II Literature Review

Regarding the research on the relationship between medical equipment management outsourcing and performance, the initial step is to define core concepts like outsourcing and performance. Subsequently, it is essential to outline the current status, primary findings, and upcoming directions of domestic and foreign scholars' investigations on these topics and their interconnection. Following this, a detailed analysis of these crucial elements is crucial. This includes retrieving, reviewing, and organizing pertinent literature, subsequently conducting a progressive investigation level by level. This study started with classical theories such as outsourcing and comprehensive equipment management, then focused on analyzing literature on outsourcing performance, performance measurement, and performance influencing factors, among others, and finally highlighted related research on the relationship between medical equipment management outsourcing and performance, and that between medical equipment full life cycle management and performance. The following literature review and commentary provide theoretical support for proposing research hypotheses and lay a theoretical foundation for building research models.

2.1 Research on Medical Equipment Management Outsourcing

2.1.1 Medical equipment management outsourcing

1. Outsourcing

Prahalad and Hamel (1990) published "The Core Competence of the Corporation" in the *Harvard Business Review*, first introducing the term "outsourcing." Academia has different opinions on the definition and scope of outsourcing. Most scholars support the following definition of outsourcing:

Because of limited internal resources, enterprises (outsourcers) tend to focus on their core businesses and outsource non-core sections to external specialized resources (contractors) to obtain greater competitive advantages, thus enhancing their ability to adapt to the environment, improving its core competitiveness, and finally achieving the goal of reducing costs and increasing efficiency.

2. Service outsourcing

Outsourcing can be categorized as “domestic outsourcing” and “offshore outsourcing” by geographical location, and as “blue-collar outsourcing” and “white-collar outsourcing,” also known as “manufacturing outsourcing” and “service outsourcing” by the nature of work. Regarding outsourcing theory, previous research mainly focuses on “manufacturing outsourcing.” With the advent of economic globalization, rapid advancements in information technology, and the growth of the high-end service industry, the service outsourcing sector has experienced substantial growth in recent years. There is no universally agreed-upon definition of service outsourcing. Stack and Downing (2005) defined it as the practice wherein enterprises transfer internal service functions to external service providers for management and control. According to *The Report on Development of China's Outsourcing* (2007), service outsourcing is described as follows: Enterprises (outsourcers) segment their fundamental, routine, and non-core information technology operations and processes from the value chain, entrusting them to external professional service providers (contractors) for the execution of economic activities.

Public service outsourcing lacks a standardized academic definition. Broadly, it is perceived as a practice wherein the government delegates services

initially offered by the government to third-party private or non-profit entities. This strategy is believed to facilitate market competition, enhance service quality and efficiency, alleviate government financial burdens, and propel service expansion and innovation. Domberger et al. (1997) argued that public service outsourcing is conducive to upholding ideology, minimizing costs, overseeing performance, implementing financial incentives and penalties, and maintaining contract control. Savas (2000) pointed out that public services are outsourced to private enterprises through contracts, which favors corporate development and reduces government pressure. Peters (2001) also recognized the positive effect of introducing a market competition mechanism into government public services, that is, adopting public service outsourcing. Common public service outsourcing forms comprise government procurement, franchising, and BOT. Among these, government procurement is widely employed in the education and healthcare sectors, as it enables the selection of top service providers through competitive bidding. Nevertheless, government procurement experiences an extended bidding period, which may foster monopolistic tendencies.

3. Medical equipment management outsourcing

While entering the era of the knowledge economy in the 20th century, foreign enterprises introduced service outsourcing based on the process re-engineering idea to improve enterprise performance and enhance core competitiveness. In Europe and the U.S., there are well-established medical equipment after-sales service systems. In addition, outsourcing management approaches have gradually penetrated medical equipment management services. Cruz and Rincon (2012) evaluated the current research status on medical

equipment management outsourcing. They found that research on operational and service management appears to have neglected the medical engineering community. They argued that the research on medical equipment management outsourcing was still in its early stages and at that time, the emphasis in research leaned towards cross-sectional surveys rather than longitudinal studies. Smithson and Dickey (2020) observed the financial performance when adopting medical equipment management outsourcing and found that a comprehensive medical equipment service management program can save significant costs for medical institutions, particularly as the procurement of new and advanced equipment for replacement continues to rise.

Domestic scholars have expressed viewpoints on the viability of post-sale socialization of medical equipment, with the prevailing notion favoring medical equipment management outsourcing as a major subject for hospital administration and third-party service providers in China in the forthcoming period. Su et al. (2005) proposed earlier that medical equipment maintenance in hospitals will have a direct impact on economic and social benefits. Exploring the feasibility of medical equipment maintenance socialization and constructing a sustainable equipment maintenance guarantee system can enhance the core competitiveness of hospitals. Li et al. (2018) analyzed the current situation of medical equipment maintenance in hospitals, proposing that outsourcing services are more efficient and reasonable. They also delved into different service collaboration modes. Yao (2019) posited that medical equipment management service and medical equipment maintenance service represent distinct concepts, and he argued that integrating medical engineering management with maintenance services will emerge as the future trend in after-

sales service outsourcing for medical equipment in contemporary hospitals. Zhao (2006) highlighted the necessity to explore and analyze the feasibility of medical equipment maintenance socialization in hospitals. While outsourcing services play a crucial role in complementing a hospital's self-maintenance capabilities, the complete elimination of the hospital's original permanent staff can lead to various challenges. These may include personnel repositioning, heightened risk in equipment management, increased management expenses, and long-term sustainability concerns, all of which warrant further discussion. It is evident that within the current medical and health service system in China, the third-party mode of medical equipment management services has been increasingly acknowledged by industry scholars, despite encountering numerous puzzles and challenges.

2.1.2 Theoretical basis of service outsourcing

As a unique form of outsourcing, service outsourcing first emerged from the IT industry and then gradually extended to logistics services, human resource management services, legal services, and other fields. Driven by the global wave of service outsourcing, scholars have been exploring the applicability of traditional outsourcing theories in service outsourcing from various perspectives. Broadly speaking, these analyses can be categorized into three main directions: (1) Management-based theories such as core competence theory, resource-based theory, and resource dependence theory; (2) Economics-based theories including transaction cost theory, comparative advantage theory, and principal-agent theory; (3) Sociological theories like social exchange theory and power theory.

As the saying goes, "All roads lead to Rome." Many scholars have

interpreted the theoretical foundation of service outsourcing from multiple perspectives. Building upon this study and drawing from classical theories within the three perspectives mentioned, four theories were selected as the foundation for this research topic, including core competence theory, resource dependence theory, transaction cost theory, and social exchange theory.

2.1.3 Service outsourcing motivations

Scholars have extensively discussed and summarized various motivations for service outsourcing, including internal driving forces within enterprises (outsourcers), external environmental factors, and internal and external interactive elements. Most studies on service outsourcing motivations center on comprehensive factor analysis. For example, Loh and Venkatraman (1992) explored IT service outsourcing motivations across four levels: macroeconomics, industry, enterprise, and inner-enterprise factors. Lacity and Willcocks (1994) highlighted that the motivations behind service outsourcing should encompass four key elements: politics, business, technology, and finance. Some scholars have examined the internal motivations of enterprises (outsourcers). For instance, Diromualdo and Gurbaxani (1998) outlined the internal driving factors influencing IT outsourcing decisions, which include cost reduction, efficiency improvement, performance enhancement, and the development and promotion of new products or services. Some scholars seek service outsourcing motivations by analyzing contextual interaction factors within and outside of enterprises. For instance, Grover et al. (1996) noted that communication, mutual trust, and collaboration between outsourcers and contractors significantly influence outsourcing decisions.

2.2 Research on Comprehensive Equipment Management

2.2.1 Comprehensive equipment management theory

In history, the development of equipment management progressed through the post-maintenance era, the preventive maintenance era, and into the era of comprehensive management. Numerous developed industrial countries across the globe have established comprehensive equipment management theoretical frameworks. While the theoretical systems in various countries have distinct emphases, most are rooted in systematics, informatics, and control science. Building on this, I introduced the comprehensive equipment management theoretical systems in the U.S., the U.K., and Japan (Han & Fu, 2012):

1. U.S.: “logistics” and “logistical engineering.” “Logistics” originates from the military field, also known as “military logistics.” At first, to control the cost of weaponry and equipment, the United States Department of Defense (DoD) adopted the Life Cycle Cost (LCC) concept from Sweden’s railway authority, grounded in a “logistics” framework. This approach mandated that the management of weaponry and equipment adhere to a minimum LCC standard, giving rise to the field of logistics engineering. In the 1960s, enterprises in the U.S. embraced “logistics engineering.” This approach became widely utilized in enterprise equipment management and was lauded by scholars as the most comprehensive discipline within equipment full life cycle management.

2. U.K.: “Equipment complex engineering.” In the 1960s, the U.K. still grappled with high maintenance costs for manufacturing equipment. Professor Dennis Parkes spearheaded a team of experts to conduct research, revealing that equipment failures resulted in substantial direct and indirect losses. Only one-

fifth of the total cost was attributable to the maintenance manager, while the majority of costs stemmed from other departments within the enterprise, which could potentially be entirely avoided. Following this research finding, Professor Dennis Parkes introduced the concept of “equipment complex engineering” at the annual International Conference on Equipment Engineering in 1971. This concept combined system theory and logistics engineering (incorporating the LCC concept). Later, in 1974, the concept evolved and was further defined as “equipment complex engineering.” The core aspects are as follows: “It represents an extensive management science integrating engineering technology, economics, and management, among other interdisciplinary subjects. It serves as a management discipline that systematically considers the full life cycle function of equipment. It involves methodologies related to equipment reliability and maintainability design. It strives to achieve the most economical full life cycle cost of equipment. It underscores the importance of information sharing and feedback in full-cycle equipment management.”

3. Japan: “Total productive maintenance (TPM).” In 1971, Japan established the theoretical framework of TPM for equipment management. Drawing from the theoretical strengths of comprehensive equipment management in the U.K. and the U.S., Japan integrated localized equipment management expertise to create a comprehensive application approach. The TPM theoretical system targets maximum efficiency, complete system integration, and the involvement of all staff members.

These theoretical systems have marked a new era in equipment management and continue to be impactful in practical applications. In the current age of rapid advancements in social science and technology, the

prevalence of modern, automated, and intelligent equipment is on the rise. It is imperative for enterprises to institute a comprehensive equipment management system to enhance economic and social outcomes.

2.2.2 Full life cycle management of medical equipment

The full life cycle theory has been widely applied across various industries regarding product, enterprise, and industry life cycles. In the field of medical equipment management, developed countries such as Europe and the U.S. started early in their research on full life cycle theory. However, the concept of full life cycle management has now been integrated into comprehensive equipment management systems across various countries.

The full life cycle management of medical equipment was implemented late in China's hospitals. The initiation of related research also lagged, and thus a comprehensive research framework has yet to be established. However, over the past 10 years, scholars have shown great enthusiasm for and recognized the full life cycle management of medical equipment. The majority view this management model as a powerful tool for ensuring the safe operation of equipment and achieving cost reduction and efficiency improvement. The volume of literature on this topic has also been on the rise annually. Zhao (2022) analyzed the problems existing in the full life cycle management of large medical equipment in Grade 3A hospitals, put forward the basic idea for establishing a full life cycle management system for medical equipment, and proposed basic measures to optimize the full life cycle management of equipment. Li (2018), Chen (2022), Huangfu (2022), and other scholars have also conducted many discussions regarding the optimization of the strategies for full life cycle management of large medical equipment in hospitals.

Other scholars carry out research on the full life cycle management of medical equipment from different perspectives and in combination with specific cases. Huang (2017) researched the path for optimizing the full life cycle management of large-scale medical equipment based on the resource allocation theory by taking Hospital A in Hunan as a case study. The research aimed to enhance the level of equipment management and foster the rational distribution of assets. Cheng et al. (2021) believed that all key links in the full life cycle should be covered in the establishment of a quality management system, aimed at optimizing the full life cycle management of medical equipment. This research took the Chinese Academy of Medical Sciences & Peking Union Medical College as a case study. Taking the First Affiliated Hospital of Soochow University as a case study, Wang et al. (2022) believed that the Clinical Skills Center's implementation of the full life cycle management of medical equipment improved the modern management level of departments.

2.3 Research on Outsourcing Performance

2.3.1 Outsourcing performance

As its Chinese name implies, performance refers to the combination of achievements and effectiveness. It represents the effective output of activities undertaken by an organization at various levels in pursuit of its objectives. As a key element in the research of economics and management, performance boasts a multitude of interpretations and applications. It is also an eternal subject fervently debated in the academic and industry sectors. Outsourcing performance is also known as cooperation performance. From the perspective of the outsourcer, it signifies that an enterprise (outsourcer) can gain more benefits after adopting outsourcing and is also satisfied with the services

provided by the contractor. From the perspective of the contractor, it refers to how the contractor completes outsourcing tasks with high quality to satisfy the enterprise (outsourcer).

2.3.2 Outsourcing performance measurement

For the measurement of outsourcing performance, domestic and international researchers in various industries and fields have provided numerous different standards. In early research, financial indicators frequently served as the sole benchmark for measuring outsourcing performance. However, the research trend suggests that researchers gradually advocate dividing performance measurements into two categories: financial and non-financial indicators. Gilley and Rasheed (2000) divided performance measurement in financial performance and non-financial performance in their research on the impact of core business outsourcing and non-core business outsourcing on enterprise performance. The non-financial performance measurement includes indicators such as quality, innovation ability, and enterprise competitiveness.

As an increasing number of enterprises shift their focus toward customer-centered value creation, more scholars are turning their attention to measuring non-financial performance from the perspective of customers. The existing literature also indicates a rising trend in the utilization of non-financial performance indicators, such as the measurement of market share, quality, and customer satisfaction. Ding et al. (2016) used two dimensions: financial performance and service performance to measure outsourcing performance in their research on e-commerce operation service outsourcing and performance. The service performance was specifically assessed by monitoring the scope of changes in service indicators (Detailed Seller Ratings, DSR) of customer

experience within the outsourcing cycle.

2.3.3 Factors influencing outsourcing performance

Decision-making involves risks. When considering the adoption of outsourcing, organizations are usually most concerned about performance issues. Studying key factors affecting outsourcing performance is of great significance for enterprises to mitigate risks, improve the success rate of outsourcing, and achieve performance objectives. Claver et al. (2002) summarized eight key factors affecting outsourcing performance. These factors were prioritized by their level of importance: the contractor's understanding of the outsourcer's objectives, senior management's support and participation, selection of appropriate contractors, good interaction and communication between the outsourcer and the contractor, the contractor's attention to and resolution of issues faced by the outsourcer, the signing of a perfect outsourcing contract between both parties, the outsourcer's comprehension of the contractor's action plan, and the outsourcing generating substantial added value.

Regarding the influencing factors of service outsourcing on performance, most of the existing researches focus on IT outsourcing. In the study on the outsourcing knowledge supply chain, Cha et al. (2008) identified knowledge sharing as an important influencing factor. Han et al. (2008) found that commitment and trust are important influencing factors in their research on enterprise abilities, relationship intensity, and outsourcing relationships. Rai et al. (2009) found that trust, communication, and collaborative problem-solving positively influence outsourcing performance, while organizational culture differences negatively impact it.

2.4 Research on the Relationship between Medical Equipment Management Outsourcing and Performance

2.4.1 Service outsourcing and performance

The definitions for outsourcing, service outsourcing, and outsourcing performance have been defined above. Now, it is pertinent to explore the relationship between service outsourcing and performance. From the existing literature, there is still a lack of large-scale empirical research on the relationship between service outsourcing and performance. Most scholars have used the theoretical framework regarding outsourcing and performance for reference in their studies, mainly presenting three conclusions:

1. Outsourcing is positively correlated with performance. Numerous studies have explained the positive correlation between non-core business outsourcing and the performance of enterprises (the outsourcer). Quinn (1994), D'Aveni and Ravenscraft (1994), Lei and Hit (1995), and other scholars confirmed that outsourcing non-core business could improve enterprise performance. In summary, the relationship between the two is reflected in three aspects: outsourcing non-core business enables enterprises to focus on core business, enhance the specialization of their business, and reduce their operating costs. Tomas and Victor's (2003) research also indicated that outsourcing enables enterprises to optimize their products and services, enhance core competitiveness, and yield positive effects on customer satisfaction, quality, innovation, and other aspects.

2. Outsourcing has no significant impact on performance. The empirical analysis conducted by Gilley and Rasheed (2000) is quite representative. They took enterprises' core business outsourcing intensity and non-core outsourcing

intensity as independent variables, performance as the dependent variable, and environmental dynamics and enterprise strategy as moderating variables to put forward four hypotheses. The research conclusions were as follows: Enterprises' core business outsourcing intensity and non-core outsourcing intensity have no significant impact on their overall performance, but the impact seemed to be overestimated in previous studies. There is no negative correlation between outsourcing intensity and innovation performance. For enterprises adopting a cost-first strategy, outsourcing intensity is positively correlated with financial performance, while for those adopting a non-cost-first strategy, the outsourcing intensity is negatively correlated with financial performance. For enterprises adopting the differentiation strategy, outsourcing intensity is positively correlated with innovation performance, while for those adopting the non-differentiation strategy, outsourcing intensity is negatively correlated with innovation performance.

3. Outsourcing is negatively correlated with performance. Ultimately, the primary motive for enterprises to choose outsourcing is to achieve positive financial and non-financial performance. However, can this strategy lead to undesirable outcomes? Teece (1997) revealed that the core business outsourcing of enterprises is negatively correlated with their innovation performance. Quinn (1992) argued that increased competition among contractors would result in a decline in the performance of the outsourcer. Wu et al. (2009) studied the relationship between R&D outsourcing and innovation performance of enterprises. They found that when the innovative R&D outsourcing intensity exceeds a certain threshold, the intensity is negatively correlated with innovation performance.

The three conclusions are quite different because they are influenced by a range of factors such as outsourcing classification, outsourcing intensity, environmental dynamics, asset specificity, and enterprise strategies. As the saying goes, “A flaw cannot hide the beauty of jade.” Many researchers believe that enterprises reasonably adopting outsourcing can bring about positive performance. Obviously, outsourcing is a “double-edged sword.” Only by understanding the key factors that affect the success of outsourcing and taking advantage of “weapons,” can enterprises make full use of their strengths and avoid their weaknesses.

2.4.2 Medical equipment management outsourcing and performance

Based on the theoretical framework of the relationship between enterprise’s non-core business outsourcing and performance, medical equipment management falls within the category of non-core business for hospitals. However, it spans interdisciplinary fields. Is the theory of outsourcing and performance relationship equally applicable in this context?

Foreign scholars started the research earlier. Tiwari (2014) evaluated the performance of a tertiary hospital that outsourced its medical equipment maintenance services. The study’s findings indicated that third-party participation could effectively enhance the efficiency of medical equipment maintenance. Masmoudi (2016) and other scholars believed that in the face of the rising complexity and costs of medical equipment, hospital managers should prioritize the restructuring of medical equipment maintenance. They argued that through outsourcing services, hospitals could achieve more effective cost management. Rios-Rincón and Haugan (2014) studied the differences between outsourcing and internal maintenance of medical equipment. The findings of a

longitudinal study on 590 maintenance transactions across 20 hospitals in Colombia showed that both outsourcing and internal maintenance have a positive impact on medical equipment maintenance performance. Moreover, the study highlighted that the spot supply of specific maintenance parts has a significant positive effect on internal and external governance. The study also found that internal governance generates better performance than external governance in public health institutions.

Domestic scholars have also made some explorations in recent years. He (2019) evaluated the effectiveness of employing an outsourcing mode for medical equipment management in hospitals. This evaluation encompassed fast response speed, short maintenance time, stable utilization rate, and low maintenance costs. Li et al. (2018) analyzed the gains and losses of medical equipment maintenance outsourcing. The "gains" include breaking the price and technology monopoly, reducing costs, responding quickly, and ensuring sufficient spare parts; the "losses" include challenges in guaranteeing the quality of services and spare parts, difficulties in accountability, and potential safety and data risks. Although researchers studied this field from different perspectives, most believed that the advantages of medical equipment management outsourcing outweigh their disadvantages. However, they also expressed concerns about the safety and effectiveness resulting from the change in the management mode.

In summary, the research on the relationship between medical equipment management outsourcing and performance primarily relies on case studies in terms of research methods. The empirical research remains in its initial stage, with a focus mainly on large-scale medical equipment or specific departments.

This is still a lack of hospital-wide, cross-hospital campus, and large-sample studies.

2.4.3 Full life cycle management of medical equipment and performance

The comprehensive equipment management theory is also very useful in the field of medical equipment management. Centering around the topic of full life cycle management and the performance of medical equipment, the theory has sparked much interest among researchers. Hospitals should strengthen the whole-process management of medical equipment, and the improvement of equipment utilization efficiency can maximize economic benefits (Beata et al., 2007). The benefit analysis of large-scale medical equipment based on the theory of life cycle cost showed that most equipment lacks quality control and preventive maintenance, leading to excessive warranty costs for hospitals. Improving the performance appraisal of medical engineering technicians is crucial to the maintenance and management of large-scale medical equipment (Chang et al., 2022). The proactive implementation of maintenance and management in the full life cycle management of medical equipment is conducive to extending the service life and ensuring the expected utilization efficiency of equipment (Qiu, 2023). Starting from the elements of comprehensive equipment management, scholars have explored a full life cycle fine management mode for medical equipment. The majority have proved that enhancing the management of key links in the full life cycle management can improve equipment performance.

Smith et al. (2013) found that performance and technological innovation are strongly affected by life cycle effects through a review of general literature and specific background literature in the field of full life cycle management of

medical equipment. Additionally, the two complementary areas of full life cycle management of medical equipment and performance were not integrated before. They are of important social and economic significance in reducing medical expenses and driving medical technological innovation.

Chapter III Research Hypotheses and Theoretical Model

In the process of writing the above-mentioned literature review, I reviewed and sorted out the research progress related to medical equipment management outsourcing, full life cycle management, and performance. In general, the empirical research on the application of outsourcing theory in the field of medical equipment management services is still insufficient. This study aims to utilize classical theories to put forward research hypotheses through theoretical derivation and build a relationship model between medical equipment management outsourcing and performance based on China's national conditions.

3.1 Theoretical Deduction

The theory of comprehensive equipment management and outsourcing is the foundational theoretical framework for this study. The following is a theoretical deduction that merges the dual paths of comprehensive equipment management with performance and outsourcing with performance. This exploration also integrates multidisciplinary fields:

1. According to the classical equipment management theory, there is a clear positive correlation between comprehensive equipment management and performance and between comprehensive medical equipment management and performance. The classic comprehensive equipment management theories of developed countries such as the U.K., the U.S., and Japan all advocate for the idea of full life cycle management. This closed-loop full life cycle management mode for medical equipment has a positive effect on performance, which has been highly recognized in the industry and academia.

2. The relationship between outsourcing and performance has yielded varying conclusions in scholarly discourse, with studies predominantly

indicating a positive correlation, a negative correlation, or no significant impact. Gilley and Rasheed (2000) pioneered the concept of outsourcing intensity (degree of outsourcing) in their study on the impact of outsourcing on enterprise performance. Subsequently, many scholars referred to the analytical framework and measurement methods to study the non-core business outsourcing of enterprises. Nevertheless, concerning the outsourcing of non-core business activities, the majority of studies have affirmed that prudent utilization of outsourcing is likely to exert a positive influence on performance. Hospitals recognize clinical medical services as their core business but consider logistics management services such as medical equipment management to be the non-core business, which can provide support and guarantees for the core diagnosis and treatment services.

3. The above-mentioned paths between comprehensive equipment management and performance and between outsourcing and performance are relatively clear, and their correlation has also been confirmed by many studies. Then what impact will be observed on performance by exploring the dual paths of comprehensive equipment management and performance, and outsourcing and performance? Does the correlation between the outsourcing of medical equipment management and performance manifest as positive, negative, or non-existent? (Figure 1)

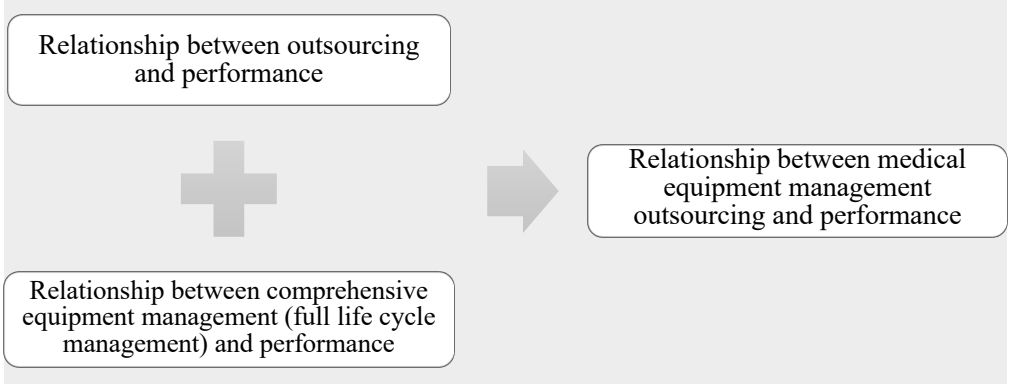

Figure 1 Path Deduction of the Relationship between Medical Equipment Management Outsourcing and Performance

4. Building upon the research model of Ding et al. (2016) on the relationship between e-commerce service outsourcing and performance, this study breaks down the degree of outsourcing into 10 links in the value chain of e-commerce operations. These links are store entry, store photography, store decoration, daily operation, marketing promotion, data analysis, internet marketing, warehousing logistics, personnel training, and channel management. Similarly, for medical equipment management outsourcing, all links of the full life cycle management are covered, and medical equipment asset management information platforms are combined, to obtain 10 measurable key activities: asset inventory, scrapping, maintenance, quality control, measurement, training, testing, routine inspection, PM, installation review and acceptance. These are embedded as the degree of outsourcing in the theoretical model of outsourcing and performance (Figure 2). If outsourcing enhances the precise management of each stage in the life cycle of medical equipment, can we deduce that it will have a positive impact on performance?

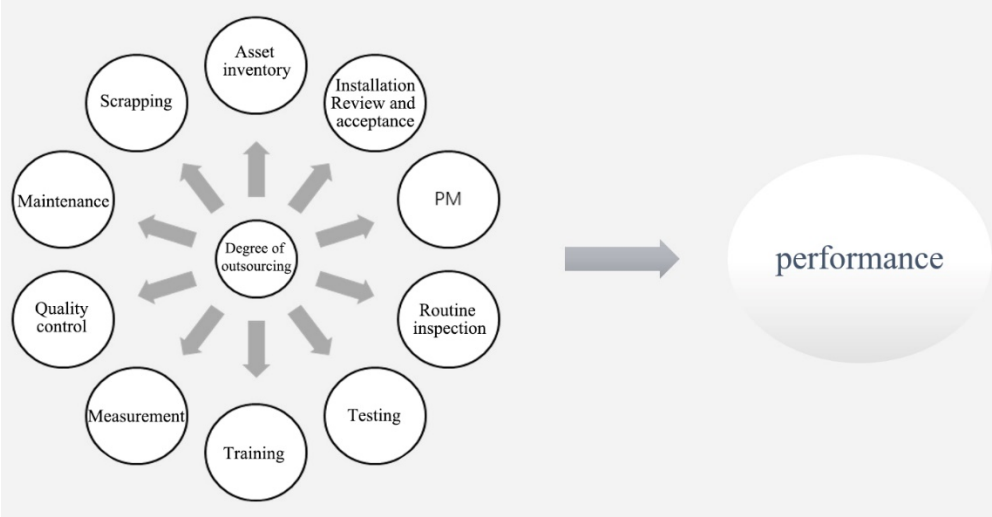

Figure 2 Theoretical Deduction of the Relationship between Medical Equipment Management Outsourcing and Performance

3.2 Research Hypotheses

By integrating interdisciplinary theories and conducting a thorough exploration level by level, we can preliminarily infer that adopting medical equipment management outsourcing and implementing the full life cycle management of medical equipment can enhance equipment performance. Therefore, this study puts forward the following hypotheses:

H1 Medical equipment management outsourcing (full life cycle management) is positively correlated with performance.

H1a Medical equipment management outsourcing (full life cycle management) is positively correlated with financial performance.

H1b Medical equipment management outsourcing (full life cycle management) is positively correlated with non-financial performance.

This study pertains to the complete outsourcing of medical equipment management services, involving all medical equipment in various campuses across the entire hospital. Scholars have also begun to focus on the relationship between medical equipment classification management and performance in

recent years. Gao and Zhang (2017) determined the medical equipment maintenance factor weight using the analytic hierarchy process (AHP). Further, they implemented the activity-based classification (ABC) method to classify medical equipment worth over RMB 200,000 in the hospital into A, B, and C categories. The method was employed to evaluate the application value of classification management for medical equipment maintenance, and the implementation countermeasures comprised preventive maintenance for category A equipment, regular maintenance for category B equipment, and post-maintenance for category C equipment. The conclusion indicated that classification management can reduce equipment failure rate, improve maintenance efficiency, and enhance service satisfaction. Liu et al. (2019) utilized the service life of medical equipment and metrics for evaluating maintenance volume, maintenance time, and maintenance cost in the ABC method. They classified the hospital's medical equipment into three categories (A, B, and C categories). The conclusion suggests that maintenance engineers need to adopt focused management strategies facing different categories of medical equipment. The different categories of medical equipment do not have a direct or independent impact on equipment performance. However, they may exert a moderating influence on the relationship between medical equipment management outsourcing and performance. Therefore, this study puts forward the following hypotheses:

H2 The medical equipment category exerts a positive regulating effect on medical equipment management outsourcing (full life cycle management) and performance.

H2a The medical equipment category exerts a positive regulating effect on

medical equipment management outsourcing (full life cycle management) and financial performance.

H2b The medical equipment category exerts a positive regulating effect on medical equipment management outsourcing (full life cycle management) and non-financial performance.

3.3. Theoretical Model

Based on the research hypotheses as well as the scope and context of this study, an overall theoretical model that explores the relationship between medical equipment management outsourcing and performance (financial performance and non-financial performance) in China's public hospitals is constructed (Figure 3).

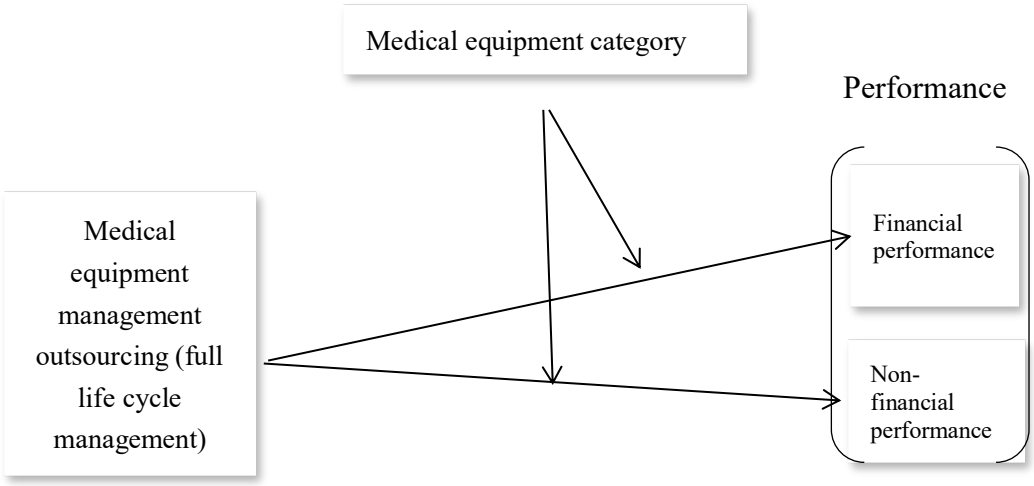

Figure 3 Theoretical Model Illustrating the Relationship between Medical Equipment Management Outsourcing and Performance

Chapter IV Research Design and Methods

4.1 Research Design

4.1.1 Research objectives

Modern medicine emphasizes “evidence-based medicine,” a principle that can be extended to explore evidence-based medical equipment management. This study aims to explore the impact of medical equipment management outsourcing and the full life cycle management model for medical equipment in China’s public hospitals on equipment performance. The specific objectives are as follows:

1. Expanding the theories about the relationship between outsourcing and performance, and between comprehensive equipment management and performance, and deducing the relationship path between medical equipment management outsourcing and performance.

2. Defining the connotation of medical equipment management outsourcing, refining key links in the full life cycle fine management of medical equipment, and establishing a structural framework for the relationship between medical equipment management outsourcing and performance.

3. Demonstrating the relationship between medical equipment management outsourcing (full life cycle management) and performance using different empirical research methods.

4. Exploring whether the equipment category has a regulating effect on the relationship between medical equipment management outsourcing and performance considering that the research subjects cover all medical equipment across various hospital campuses.

5. Providing theoretical and practical basis for the high-quality

development of medical equipment operation and management in China's public hospitals based on China's national conditions and management practice.

Based on the above research objectives, the overall technical route of this study is designed (Figure 4), including aspects such as research background, topic selection, research conception, and research conclusions.

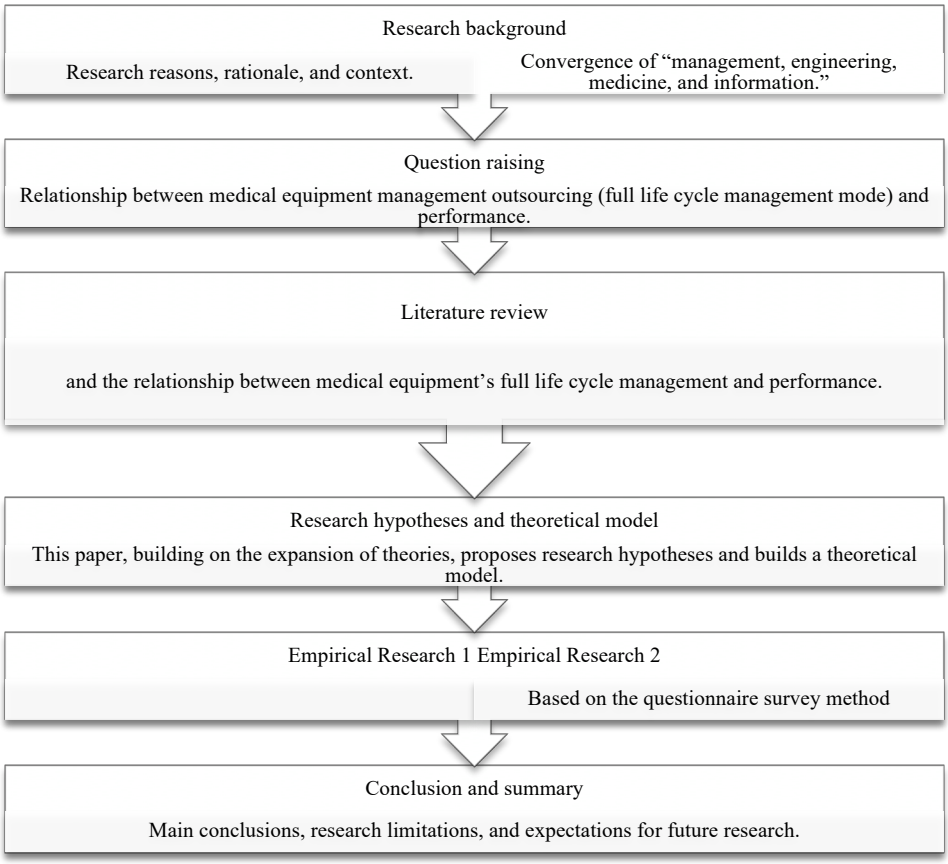

Figure 4 Technical Route of This Study

4.1.2 Research scope

1. Core concepts

(1) Public hospitals

Public hospitals generally refer to medical institutions directly funded or controlled in shares by the government or state-owned enterprises. According to the *China Health Statistical Yearbook 2020* (2021), public hospitals are defined in the main indicator explanations as hospitals whose economic type is

state-owned or collective-owned. China's public medical and health institutions can be divided into three categories: public hospitals, primary medical institutions, and public health institutions. *The Guiding Opinions on Establishing a Modern Hospital Management System* clarifies the establishment of a modern hospital management system with Chinese characteristics, and *The Opinions on Strengthening Party Building in Public Hospitals* (2018) clarified the governance structure of public hospitals in China, that is, the president responsibility system under the leadership of the Party Committee.

Clarifying the operation systems and attribute characteristics of China's public hospitals is of great significance for studying the relationship between medical equipment management outsourcing and performance. They exhibit several key features: First, public hospitals maintain a dominant position in China's medical service system and play a pivotal role in protecting people's health. Private hospitals have experienced significant growth with the support of policies in recent years and their number has surpassed that of public hospitals. However, public hospitals maintain a considerable lead in terms of various indicators such as the number of patients receiving diagnosis and treatment, the number of beds, the number of medical and health professionals, and the number of discharged patients. Second, public hospitals are non-profit medical institutions characterized by a strong commitment to public welfare and social benefits. However, this attribute does not imply that they neglect the pursuit of efficiency. Third, public hospitals are public institutions based on balance allocation. Thus, the financial allocation only accounts for a tiny fraction of a hospital's revenue. After the implementation of the zero markup on drugs and consumables, most hospitals have achieved replacement, structural

adjustments, and upgrades by adjusting medical service prices. Fourth, the staffing of public hospitals is mainly divided into permanent employees and contract employees. The remuneration system for employees is based on the unified salary system, standards, and policies of public institutions, showing a large gap with that for medical personnel in developed countries.

(2) Medical equipment management outsourcing

Currently, the international after-sales management service providers of medical equipment usually include three categories: original equipment manufacturers (OEMs), independent service organizations (ISOs), and hospital in-house clinical engineering departments. The three types of service providers have distinct advantages and disadvantages, and it is increasingly common to see combined services provided by them through cooperation.

Medical equipment management outsourcing is still in its initial stage in China, and its concepts, norms, and standards have not yet been defined uniformly. The medical equipment management outsourcing discussed in this study is defined as the comprehensive trusteeship service provided by a third-party organization, a management service model that covers all medical equipment throughout an entire hospital. The project's overall framework is intricately intertwined with the concepts of full life cycle management and lean management of medical equipment. Leveraging medical engineering management services as the content, and relying on a mobile internet-powered intelligent management platform, a housekeeper-style service platform dedicated to the full life cycle management of medical equipment is crafted. The project reconfigures the internal organizational structure and resource elements of the hospital based on factors such as hospital size, asset situation, and service

content. It establishes a third-party medical equipment management service center to implement personalized comprehensive management service solutions. However, the original Medical Engineering Department or Equipment Department of the hospital retains only key management and supervision positions to supervise and assess third-party teams.

(3) Full life cycle management of medical equipment

The full life cycle management of medical equipment refers to the closed-loop management centering on the safe operation of equipment and covering the full life cycle of medical equipment. Lesniak (2015) posited that the full life cycle management of medical equipment should be based on the specific needs of clinical departments. This approach commences with the purchase requisition demonstration, benefit assessment, and procurement budget. It then progresses to the application links encompassing installation review and acceptance, repair and maintenance, and training and education. It concludes with post-processing regarding equipment allocation and scrapping. All these are conducive to the effective full life cycle management of medical equipment. It is also clearly mentioned in the requirements for grade accreditation of China's public hospitals that comprehensive management of medical equipment should cover the full life cycle of equipment, integrating all links of the cycle into fine management.

2. Research scope

After the above core concepts are clarified, this study examines the impact of medical equipment management outsourcing and the full life cycle management model on equipment performance in China's public hospitals. Empirical Research 1 selects two hospitals: Hospital A, which has engaged in

medical equipment management outsourcing, and Hospital B, which has not adopted medical equipment management outsourcing. The scope of this research encompasses all medical equipment in multiple campuses of Hospitals A and B. As a Grade 3B public hospital, Hospital A is both a leading unit of the regional medical community and a member unit of the medical alliance. Additionally, it is also an affiliated teaching hospital of a university, exemplifying the advancement in the deepening reform process and innovative management practice of public hospitals in China. Empirical Research 2 also selects Hospital A, covering all medical equipment in multiple campuses of the hospital.

4.1.3 Measurement items of variables

According to the above research hypotheses and theoretical model, this study clarifies the connotation and measurement items of each variable. It employs a range of empirical research methods to validate and demonstrate various variables and their relationships. The variables and measurement items involved in this study primarily originate from several sources: directly citing the literature maturity scale; modifying the maturity scale based on the analysis of relevant literature and theoretical research, combined with the specific situation of this study; some variables have abstract constructs that cannot be directly observed and need to be measured through measurable indicators. These variables are developed based on existing scales, in combination with medical equipment management service and operation practices in the hospital.

The variables-related scale in this study, along with the sources, is shown in Table 1, including medical equipment management outsourcing (full life cycle management), which is the explanatory variable; equipment performance

(financial performance and non-financial performance), which is the explained variable; medical equipment category, which is the moderating variable; equipment unit price, service life, and origin of place, which are control variables.

Table 1 Research Scale and Sources

Variable		Measurement item	Reference
Medical equipment management outsourcing (full life cycle management)		Asset inventory, installation acceptance, preventive maintenance, routine inspection, training, measurement, testing, maintenance, quality control, and scrapping.	Lesniak (2015)
Equipment performance	Financial performance	Utilization rate (the rate of equipment in good condition)	Tiwari (2014) and Masmoudi (2016) He (2019) and Yang (2020)
	Non-financial performance	Satisfaction (clinical satisfaction)	Wang (2021) and Yang (2020)
Medical equipment category		Medical equipment management risk categories	*Regulation on the Supervision and Administration of Medical Devices* (2021)

1. Explanatory variable

The explanatory variable in this study is the medical equipment management outsourcing (full life cycle management). The definitions of medical equipment management outsourcing and full life cycle management of medical equipment have been elaborated in the section on core concepts. In the literature, there is a scarcity of empirical research on medical equipment management outsourcing, and maturity scales that can be directly used for measurement are lacking. Therefore, this study draws on measurement indicators and methods from mature sub-fields of service outsourcing. It combines the characteristics of the medical equipment management field and uses key link activities in the full life cycle management of medical equipment to measure explanatory variables.

In the classic literature research, Lesniak (2015) posited that the medical equipment full life cycle management theory should first focus on clinical needs and the full life cycle management of equipment should span the early, middle, and final stages. Additionally, Chen (2022) believed that the construction of a performance-oriented full life cycle management platform for medical equipment can increase the benefits of medical equipment while controlling costs. Wang et al. (2022) proposed that the implementation of personalized full life cycle management of medical equipment in hospitals' skills centers can continuously optimize management decisions, improve the utilization efficiency, reduce operating costs, and enhance the modern management level of departments by collecting and analyzing equipment operation data. For the construction of the full life cycle management system for medical equipment based on information platforms (Figure 5), it is required to systematically monitor and manage the information in each link. This approach mainly includes important modules such as equipment application, bidding, procurement, installation, review and acceptance, training, routine inspection, PM, measurement, testing, maintenance, quality control, risk assessment, and scrapping. To facilitate comprehension and measurability, this study identifies 10 key indicators from systematic modules as specific measurement items of the explanatory variable. These indicators are asset inventory, installation review and acceptance, preventive maintenance, routine inspection, training, measurement, testing, maintenance, quality control, and scrapping.

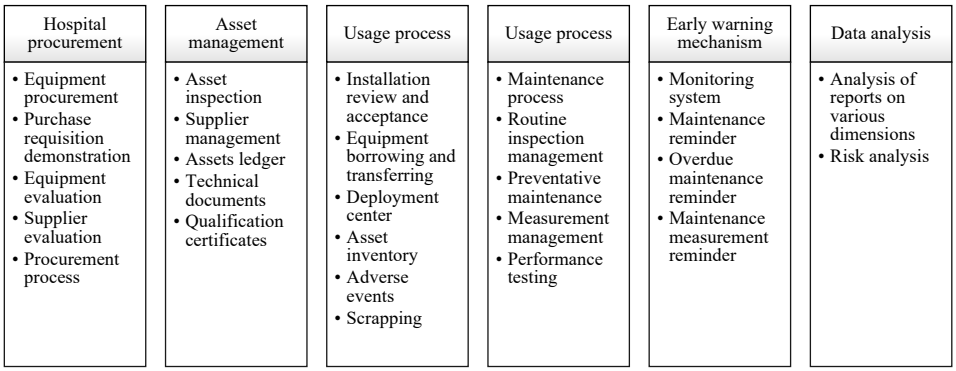

Figure 5 Full Life Cycle Management System for Medical Equipment Based on Information Platform

2. Explained variable

This study considers equipment performance as an explained variable. The existing literature shows limited descriptions of equipment performance indicators, and a commonly recognized measurable indicator system is lacking. The prevalent indicators typically revolve around equipment management efficiency or its potential substitutes. Xiao et al. (2005) suggested employing the equipment utilization rate to gauge enterprise equipment effectiveness, while Deron and Rooda (2006) and Zammori et al. (2014) proposed utilizing the overall equipment effectiveness (OEE) method to gauge equipment effectiveness. Certain scholars argued that measuring equipment performance solely through a singular indicator is challenging, suggesting a comprehensive evaluation approach considering multiple perspectives. Banker et al. (2006) proposed employing three-dimensional indicators—equipment quality, response time, and equipment effectiveness—to evaluate equipment performance. Tiwari (2014) and Masmoudi et al. (2016) assessed the performance of medical institutions implementing medical equipment management outsourcing. They found the role of outsourcing interventions in reducing operation and maintenance costs and enhancing operational efficiency.

Yang et al. (2020) established a control group and an observation group based on varying management cycles of medical equipment inside and outside the hospital. They conducted evaluations using a benefit evaluation method. The equipment utilization rate of the observation group was superior to that of the control group. The equipment utilization rate typically represents the proportion of actual equipment runtime to the expected working time, commonly used to assess equipment operational quality and reflect equipment investment returns. Enhancing the rate may lead to improved financial performance. Since this study involves all medical equipment in the entire hospital, except for some large equipment with fee-based services that can be charged based on usage frequency, most equipment cannot be directly accounted for or demonstrate revenue generation. Moreover, it is essential to consider both economic and social benefits when evaluating medical equipment. Some equipment, like defibrillators, ECMO machines, and other life support and first aid devices, are not directly assessed using the utilization rate. Instead, they are better represented using the rate of equipment in good condition. This study selected the equipment utilization rate as a management efficiency indicator for assessing the financial performance of medical equipment. The equipment utilization rate mentioned here specifically pertains to the rate of equipment in good condition. For instance, achieving an equipment utilization rate of 95% implies that the equipment can operate normally for a minimum of 346 days annually out of 365 days, with downtime accounting for less than 5%.

Customer satisfaction indicators, commonly employed to evaluate the non-financial performance of service outsourcing, have exhibited an upward trend in recent years. Wang et al. (2021) delved into a novel approach to diversified

medical equipment management. In addition to indicators like fees and efficiency, they introduced the indicator of clinical satisfaction. The findings indicated that the observation group outperformed the control group in terms of maintenance timeliness, maintenance costs, and clinical satisfaction. Yang et al. (2020) also verified that the observation group surpassed the control group regarding customer satisfaction. The satisfaction indicator assesses the degree of contentment among staff across clinical departments concerning the quality and efficiency of medical equipment management services, as well as utilization of medical equipment. The study used the clinical satisfaction indicator to gauge the non-financial performance of medical equipment.

Given that the explained variable equipment performance ought to mirror management efficiency and outcomes, this study, following literature review, analysis of measurement indicators and methods, field research, and expert opinions, assessed the financial and non-financial performance of equipment using the equipment utilization rate and clinical satisfaction indicator to align with the overarching performance goals of cost reduction, benefit enhancement, and service advancement.

3. Moderating variable

This study employed the medical equipment category as the moderating variable. Scholars proposed diverse measurement indicators for the medical equipment category based on varying medical equipment classification methods. Liu (2019), Gao and Zhang (2017), and Huang (2021) each utilized a holistic score evaluating medical equipment service life and factor weight to categorize equipment into A, B, and C categories featuring different maintenance management strategies.

Many countries categorize medical equipment based on varying risk levels. For instance, the FDA in the U.S. classifies medical equipment into Class I, Class II, and Class III; CE in Europe classifies medical equipment into Class I, Class IIa, Class IIb, and Class III; and China's NMPA classifies medical equipment into Class I, Class II, and Class III. Based on the national conditions and research context, this study adopted the NMPA medical equipment risk categories as a specific measurement item for the moderating variable, considering indicator standardization, measurability, and ease of understanding by respondents. Per the *Regulations on the Supervision and Administration of Medical Devices (2021)* issued by the State Council, medical devices are categorized into three groups based on varying levels of management risks: Category I denotes devices with low risk, requiring routine management for safety and effectiveness; Category II signifies moderate-risk devices requiring stringent control and management for safety and effectiveness; Category III encompasses high-risk devices necessitating special measures for strict control and management to guarantee safety and effectiveness.

4. Control variable

The control variables include equipment unit price, service life, and equipment's place of origin. Medical equipment management outsourcing is a complex, multidisciplinary research field influenced by numerous factors. This study delved into the impact exerted on equipment performance through the lens of full life cycle management within the outsourcing mode. Medical equipment management outsourcing may be affected by some variables, such as equipment unit price, service life, and origin of place. Based on existing literature and hospital operation practices, it is generally observed that a higher unit price of

equipment likely exerts a stronger influence on financial performance; the extended service life of equipment may have a more significant impact on performance; furthermore, a higher proportion of imported equipment may also yield a more notable effect on performance.

These critical attributes of medical equipment discussed above may significantly impact equipment performance. Hence, this study chose three control variables linked to the performance of medical equipment management outsourcing. The specific measurements include unit price of equipment, denoting the percentage of equipment priced above RMB 100,000; service life of equipment, denoting the percentage of equipment aged over 10 years; equipment's origin of place, denoting the percentage of imported equipment.

4.2 Empirical Research 1 (Based on DID Model Method)

4.2.1 Research object

1. Hospital A

(1) Introduction to Hospital A

Established eight decades ago, Hospital A has developed into a comprehensive Grade 3B public hospital integrating medical treatment, prevention, rehabilitation, healthcare, teaching, and scientific research. Covering an area of approximately 66,666.67 square meters and boasting a construction expanse of around 140,000 square meters, the hospital is an affiliated teaching hospital of several universities, directly and indirectly associated with national educational authorities. It has 45 clinical medical technology departments, 36 open wards, and over 1,000 open beds. The hospital employs more than 1,700 staff members, including over 300 with senior and sub-senior professional titles, and more than 300 with master's and doctoral

degrees. Over the past few years, Hospital A has consistently prioritized patient and staff values, staying committed to fostering a culture of embracing the future with innovation. With collective efforts and a striving spirit, the hospital has achieved remarkable outcomes in advancing the building of a close medical alliance and constructing a county-level medical community. It has received multiple honorary titles, including National Youth Model Unit, National Women's Demonstration Unit, National County-level Medical Community Demonstration Unit, Provincial Green Hospital, and Provincial Civilized Unit.

As a regional medical diagnosis and treatment center, the hospital is equipped with a regional imaging center, an electrocardiogram diagnostic center, an ultrasound diagnostic center, a pathology diagnostic center, a quality control center, and a clinical skills training center. It shoulders the responsibility of providing comprehensive, full-cycle medical and health services for the people in the entire region. At the beginning of 2019, Hospital A, as the leading unit of regional hospitals, partnered with three community health service centers to jointly establish a regional medical community, coordinating the unified management of personnel, funds, and properties, and actively improving the ability of primary medical and health services. To further leverage its leading role as a regional medical and health hub and meet the increasing demand of people for high-quality medical resources, the hospital envisioned its creation of a first-class regional medical community and a Grade 3A hospital, achieving transformative high-quality development and establishing a demonstration area for common prosperity in health services.

Before July 2020, Hospital A had not implemented medical equipment management outsourcing. The expansion of medical equipment (hard power)

and the weakening in equipment management (soft power) posed significant challenges to the hospital in high-quality, sustainable development. The latest standards for hospital-grade accreditation and the new regulations on medical equipment management have introduced heightened management requirements and standards across the entire spectrum of hospital medical equipment, including repair, maintenance, routine inspections, measurement, and daily management. As medical diagnosis and treatment increasingly rely on medical equipment while demanding higher after-sale service of medical equipment, the conflict between medical equipment management and high-quality hospital development has become increasingly pronounced. Hospital A encounters the following management challenges regarding its medical equipment: The medical equipment management department holds a subordinate position compared to clinical diagnosis and treatment departments, resulting in its weakened departmental oversight; the equipment department faces a scarcity of specialized engineering and technical personnel, particularly clinical medical engineers specializing in radiology and hemodialysis equipment; insufficient professional expertise and subpar maintenance efficiency can hardly ensure the safe and effective operation of hospital's medical equipment, hindering coordination of medical equipment maintenance across all hospital campuses; there is the absence of medical equipment asset management software and a structured medical equipment management and maintenance system, coupled with some missing entries in medical equipment asset management records and documents; reliance on original manufacturers for maintenance of Class B large equipment and endoscope equipment results in limited self-repair capabilities and high spare parts costs and maintenance expenses; equipment department

staff have no adequate opportunities for training in new technologies and continuing education, alongside constraints in salaries, acquiring the permanent employee status, and promotion opportunities; branch hospitals within the medical community lack dedicated medical equipment management personnel, which leads to fragmented equipment management practices and a lack of standardized protocols.

(2) Overview of medical equipment assets

Since the establishment of Hospital A as a regional diagnosis and treatment center at the beginning of 2019, it has witnessed rapid growth in its scale of medical equipment asset management. Based on the medical equipment asset management records in June 2020, the main hospital campus and three campuses within the medical community had over 2,800 pieces of registered medical equipment (each with an original value exceeding RMB 1,000).

Regarding the quantity proportion of medical equipment across different departments, the top three within the hospital include the intensive care unit (8.44%), operating room (6.37%), and pediatric inpatient department (5.18%). In terms of the amount proportion of medical equipment across different departments, the top three within the hospital are the radiology department (23%), operating room (14%), and intensive care unit (8%). Despite the radiology department at the main hospital campus having 1.09% of the hospital's total equipment count, the equipment's value represents 23% of the hospital's total, marking the highest among all clinical departments. Class B large medical equipment is predominantly allocated in the radiology department. Moreover, concerning the amount proportion of medical equipment across hospital campuses, a significant concentration of medical equipment is observed

in the main hospital campus, whereas medical equipment is sparsely distributed in hospital campuses within the medical community, with lower equipment asset values.

(3) Overview of implementing medical equipment management outsourcing

Amid the advancement of institutional reforms within public institutions and the deepening specialization of social labor divisions, it is necessary to enhance the overall hospital medical equipment management and provide better clinical services while reducing financial expenditure in line with medical equipment management standards and requirements. In June 2020, Hospital A launched a tender for medical equipment management outsourcing, intending to guarantee the safe and efficient operation of all medical equipment. The project's service scope encompassed all high-value medical equipment listed in the hospital's fixed assets and low-value medical equipment not listed within the hospital's fixed assets.

In July 2020, the management service provider winning the bid established a third-party medical equipment management service center within Hospital A premises. The project's operational framework is intricately intertwined with the principles of full life cycle management and lean management of medical equipment. Leveraging medical engineering management services as the content, and relying on a mobile internet-powered intelligent management platform, a housekeeper-style service platform dedicated to the full life cycle management of medical equipment was crafted. (Figure 5). The main system comprises a medical equipment management platform, a spare parts supply chain management platform, and a clinical medical engineer management

platform. These three platforms can operate autonomously or synergistically to provide comprehensive services across all PC and mobile terminals.

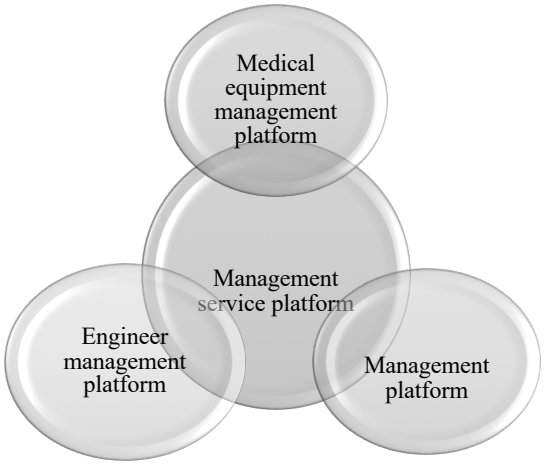

Figure 5 Structure of Medical Equipment Management Service Platform

Based on the comprehensive asset inventory of medical equipment across the four hospital campuses, all the equipment (each originally valued at over RMB 1,000) with no discrepancy between the accounts and facts was tagged with barcodes or radio-frequency identification (RFID), with corresponding data entered into the third-party asset management system to facilitate effective management of the medical equipment's full life cycle data. According to the hospital's background and medical equipment assets, a personalized management service plan was devised, the organizational structure and resource factors were realigned, and a full life cycle management service system for medical equipment was established. Main services are shown below (Table 2).

Table 2 Main Services of Medical Equipment Management Outsourcing

Management system	Service
Hospital service center management	Hospital team management, service center's site management, spare machine management, warehouse management of spare parts and consumables, repair and customer service management.
Data management	Supplier management, department management, classification management of equipment and spare parts, user management, and other basic data management.
Contract management	Management of purchase contracts, repair contracts, maintenance contracts, and service contracts.
Asset management	Unified management of basic information throughout the full life cycle of equipment assets from procurement to scrapping.
Process management	Repair management, maintenance management, routine inspection management, measurement management, testing management, etc.
Risk management	Quality management, adverse event and safety incident management, early warning management, etc.
Report management	Equipment utilization rate, benefit analysis, repair rate, cost analysis of maintenance and spare parts, etc.
Information management	Medical equipment asset information system management, HIS, LIS, PACS, WMS interface management, app and mini program management, etc.

2. Hospital B

Before any intervention, there might be pre-event differences within the grouped samples of quasi-natural experiments, and complete randomization of medical equipment among different hospitals is unfeasible. After Hospital A is designated as the intervention group, Hospital B, which has not adopted medical equipment management outsourcing and not implemented full life cycle management of medical equipment, is selected by comparing background information. The hospitals A and B exhibit congruence in key indicators such as hospital attribute, hospital grade, the number of medical technology departments, the number of available inpatient wards, available bed count, annual outpatient and emergency visits, and annual discharges (Table 3). Hospital B's entire medical equipment is set as the control group.

Table 3 Background Comparison of Hospitals A and B

Hospital	Hospital Attribute	Hospital Grade	Medical technology department	Available inpatient wards	Available beds	Annual outpatient and emergency visits (10,000)	Annual discharges (10,000)
Hospital A	Public	Grade 3B	45	36	1,010	156	4.95
Hospital B	Public	Grade 3B	35	30	1,102	106	5.10

4.2.2 Data collection

All research data related to medical equipment in Hospitals A and B were collected in the year before and after the commencement of the outsourcing intervention in July 2020, namely July 2019 as the initial data time and June 2021 as the concluding data time. Newly acquired and decommissioned equipment between July 2019 and June 2021 were excluded. Due to the substantial volume of original panel data and occurrence of repetitions, the medical equipment of Hospitals A and B was sorted by name, with 356 valid samples for the intervention group and 420 valid samples for the control group.

Data related to medical equipment assets and operations were sourced from the third-party medical equipment management service information platform, the hospitals' medical equipment asset management systems, and records from the medical equipment management. Furthermore, clinical satisfaction data was derived from the monthly results of the medical equipment management satisfaction surveys conducted across various wards and departments.

4.2.3 Analysis method

Ashenfelter from Princeton University (1985) pioneered the integration of the DID model into project impact evaluation studies, validating the causal link between intervention implementation and project effect through linear model

frameworks. Subsequently, the DID model found increasing application across econometrics, public policy implementation, project impact evaluation, and other research domains. Yip and fellow scholars from Harvard University were among the first group of people to introduce the DID model into healthcare research. The DID model, capable of producing quantitative results of intervention effects and addressing limitations in existing studies yielding solely qualitative outcomes, has gained growing application in the medical and public health sectors. Ye et al. (2013) reviewed studies on the DID model application in the healthcare domain from 2001 to 2011, identifying 124 pieces of academic literature. While the literature quantity was modest in China, an upward trend was exhibited annually. These studies mainly focused on policy assessments, event impacts, and intervention evaluations. Zhao et al. (2018) and Xu et al. (2021) conducted an empirical exploration of public health management using the DID model.

In alignment with the quasi-natural experiment sample characteristics, the medical equipment of Hospital A formed the intervention group samples, while that of Hospital B constituted the control group samples. They were categorized into pre-intervention (July 2019–June 2020) and post-intervention (July 2020–June 2021) periods based on the outsourcing intervention time point in July 2020. This study applied the DID model to examine the net impact of medical equipment management outsourcing on performance by comparing performance variations before and after the intervention within the intervention group, as well as those between the intervention and control groups.

$$Y = \beta_0 + \beta_1 Group + \beta_2 Year + \beta_3 Group * \text{year} + \beta_i X_i + \varepsilon$$

Y is the explained variable, representing equipment performance including financial and non-financial performance. Group denotes the group-oriented dummy variable, with 0 assigned to the control group and 1 to the intervention group. Year serves as the time-oriented dummy variable, with 0 appointed for pre-outsourcing intervention and 1 for post-outsourcing intervention. The group × year signifies the interaction term of group- and time-oriented dummy variables. Xi signifies observable control variables, denoting equipment unit price, service life, and origin of place, respectively.

4.3 Empirical Research 2 (Based on Questionnaire Survey Method)

4.3.1 Research object

1. Research object and questionnaire design

Aligned with the research topic and the accessibility of hospital staff to medical equipment management services, the questionnaire survey method effectively elucidates the correlation between medical equipment's full life cycle management and performance under an outsourcing mode. Hence, Hospital A's medical equipment was selected, with hospital staff as respondents. The questionnaire was distributed to all potential respondents across the hospital, including those from medical technology departments, clinical departments, functional management departments, and other sections. The questionnaire was designed to collect essential data for empirical validation related to the impact of the implementation of medical equipment management outsourcing and full life cycle refined management in the hospital on equipment utilization rate and clinical satisfaction levels, and the regulatory effect of equipment categorization.

The questionnaire consisted of five parts: basic personal information, full

life cycle management of medical equipment, equipment utilization rate, clinical satisfaction, and medical equipment category, comprising 41 questions. Specific details on items and corresponding variables are shown in Table 4. Answer options were displayed using the 5-point Likert scale. Concerning questions concerning the explanatory variable, explained variable, and moderating variable, respondents were requested to rate their actual perceptions regarding the implementation of medical equipment management outsourcing and the adoption of a full life cycle management mode at the hospital on a scale from 1 to 5. These ratings were utilized as the foundation for empirical analysis.

Table 4 Questionnaire Item Setting

	Item	Corresponding variable	Quantity
Part I	Basic personal information	Individual characteristics of the respondent	5 questions
Part II	Full life cycle management of medical equipment	Explanatory variable	10 questions
Part III	Utilization rate of equipment	Explained variable	10 questions
Part IV	Satisfaction	Explained variable	10 questions
Part V	Medical equipment category	Moderating variable	6 questions

2. Pre-survey

A pilot small-scale survey was conducted at Hospital A to justify the content and logic of the questionnaire and ensure the feasibility and effectiveness of subsequent research endeavors. Given that the number of small-scale questionnaires should equal or exceed the number of questions, paper questionnaires were dispensed and gathered on site. A total of 50 questionnaires were distributed across select departmental inpatient wards at Hospital A, with 47 collected on the same day. After discarding two invalid responses, 45 valid questionnaires remained. The effective questionnaire collection rate reached

90%, meeting the requirements for research data analysis.

The reliability and validity analyses were conducted using SPSS statistical software. According to feedback from hospital respondents, terminologies featured in the questionnaire were elucidated, such as full life cycle management of medical equipment and risk categories in medical equipment management, to enhance comprehension. Additionally, modular editing was implemented for setting questionnaire items, aiding hospital staff in saving time and ensuring efficient and accurate questionnaire completion. Subsequent analysis was conducted using SPSS software, confirming that the overall reliability and validity of the questionnaire remained unaffected after modification. This outcome allowed for further investigation.

3. Large-scale sample survey

The finalized questionnaire (see Appendix for details) and the informed consent form were approved by the IRB in August 2023 before being distributed and collected on-site at Hospital A in September 2023. Considering the representativeness and diversity of respondents, and the reliability of data acquisition, the survey tried to cover all department and inpatient ward staff within the hospital, including all potential participants in areas like medical technology departments, clinical departments, and functional management departments.

4.3.2 Data collection

Within three days, 300 questionnaires were distributed, with 288 collected. Among these respondents, 64 exhibited a good understanding of the full life cycle management of medical equipment, 217 had some degree of understanding, and seven lacked understanding. Since data from the seven

questionnaires from respondents with no understanding of the full life cycle management of medical equipment holds no reference value for research outcomes, and another three questionnaires contained erroneous or missing information, these 10 invalid questionnaires were disregarded. Consequently, the final valid questionnaires for this study stood at 278, showcasing an overall effective questionnaire rate of 93%.

4.3.3 Analysis method

For Empirical Research 2, SPSS 24.0 software served as the statistical analysis tool for the reliability, validity, correlation, and regression analyses of the collected data.

1. Reliability analysis

Reliability analysis aims to examine the reliability and result consistency of scale through repeated measurements of the same object using the same methodology. Cronbach's alpha, also known as coefficient α, is the most utilized method for measuring reliability, overcoming limitations associated with the split-half method. Considering it as the most commonly used reliability analysis method in social science research, this study employed the reliability coefficient α to evaluate reliability.

2. Validity analysis

Validity analysis serves to confirm the precision and authenticity of the questionnaire. This study employed the Kaiser-Meyer-Olkin (KMO) and Bartlett's test to assess if the scale data are suitable for subsequent factor and correlation analyses.

3. Correlation analysis

Correlation analysis measures the degree of correlation between two or

more variables, employing correlation coefficients to evaluate the significance of relationships among different variables. This study employed the Pearson correlation coefficient to assess correlations among independent, dependent, and moderating variables, verifying the presence of any significant relationships among these variables.

4. Regression analysis

A regression model was constructed to ascertain the interconnected quantitative relationship among variables. This study utilized statistical software to perform regression analysis on the variable relationships, testing the hypotheses.

Chapter V Result Discussion

5.1 Empirical Research 1

5.1.1 Descriptive statistical analysis

Analysis was conducted using the statistical software Stata. The cross-summary table (Table 5) illustrates the distribution of sample data within each group. Before and after the event, the intervention group had 356 samples, while the control group had 420 samples.

1. Before/after outsourcing intervention event

Before the event (Before)—time=0; after the event (After)—time=1.

2. Control group/intervention group (treated group)

Control group (Control) represents no outsourcing intervention—treat=0; treated group (Treated) represents outsourcing intervention—treat=1.

Table 5 Cross-summary Table of Grouped Samples

	Before	After	Summary
Control	420	420	840
Treated	356	356	712
Summary	776	776	1,552

5.1.2 Effect evaluation of utilization rate

The DID effect of medical equipment management outsourcing on utilization rate is as follows (Tables 6 and 7):

Table 6 T-test

Item	Control	Treated	Diff	t	p
Utilization rate (Before)	6.079	6.081	.003	.052	.958
Utilization rate (After)	6.157	6.441	.264	5.191	.000***

Table 7 Regression Results of the Impact of Medical Equipment Management Outsourcing on Utilization Rate

	(1)	(2)	(3)	(4)
VARIABLES	Y	Y	Y	Y
Post	.079	.079	.079	.079
	(1.455)	(1.493)	(1.502)	(1.563)
Treat	.003	-.060	-.035	-.062
	(.051)	（-1.088）	(-.634)	(-1.163)
Post×Treat	.281***	.281***	.281***	.281***
	(3.523)	（3.617）	(3.637)	(3.785)
Unit price		.382***	.952***	.216
		(9.198)	(6.748)	(1.440)
Service life			-.609***	-.594***
			(-4.223)	(-4.290)
Place of origin				.819***
				(11.384)
Constant term	6.079***	5.978***	5.968***	5.887***
	(159.150)	(154.235)	(154.525)	(155.728)
Observations	1552	3104	4656	6208
R-squared	.033	.083	.093	.164
p	.000***	.000***	.000***	.000***

Note: ***, **, and * indicate that variables are significant at the significance levels of .01, .05, and .1 respectively. The value in parentheses is t, and Y is the explained variable, representing equipment performance

1. DID model evaluation of utilization rate without control variables

Table 6 indicates that before the intervention, the DID effect value of the treated and control groups corresponds to p= .958> .05 of the t-test, which suggests no significant difference. This finding implies that before the experiment, no notable difference in effect level existed between the treated and control groups, indicating adherence to the parallel trend assumption by the samples.

Table 6 indicates that after the intervention, the DID effect value of the treated and control groups corresponds to p= .000< .05 of the t-test, which

suggests a significant difference. This finding shows that after the experiment, the treated group's effect value is notably higher than that of the control group.

Table 7 reveals that the ultimate DID effect value is 3.523, corresponding to p= .000< .01 of the t-test, which suggests a significant difference. This signifies a significant DID effect with an average effect value of 3.523. The outcomes of the DID value suggest that implementing medical equipment management outsourcing contributes to enhancing the equipment utilization rate.

2. DID model evaluation of utilization rate with the control variable of equipment unit price

Control variables related to the performance of medical equipment management outsourcing include equipment unit price, service life, and place of origin.

Considering equipment unit price as a control variable in the DID regression model, Table 7 shows the DID effect value is 3.617 corresponding to p= .000< .01 of the t-test, which suggests a significant difference. This signifies a significant DID effect and the role of outsourcing intervention in increasing utilization rate, with an average effect value of 3.617. When compared to the evaluation outcomes of the DID model excluding the control variable (t=3.523, p< .001), the net effect increases with the inclusion of the unit price as a control variable (t=3.617, p< .001). Therefore, the result underscores the practical importance of the control variable, equipment unit price, in assessing the utilization rate. A higher unit price correlates with a potentially stronger impact of medical equipment management outsourcing on the utilization rate.

3. DID model evaluation of utilization rate with the control variable of equipment service life

Considering equipment service life as a control variable in the DID regression model, Table 7 shows the DID effect value is 3.637 corresponding to p= .000< .01 of the t-test, which suggests a significant difference. This signifies a significant DID effect and the role of outsourcing intervention in increasing utilization rate, with an average effect value of 3.637. When compared to the evaluation outcomes of the DID model excluding the control variable, the net effect increases with the inclusion of the service life as a control variable (t=3.637, p< .001). Therefore, the result underscores the practical importance of the control variable, equipment service life, in assessing the utilization rate. A longer service life correlates with a potentially stronger impact of medical equipment management outsourcing on the utilization rate.

4. DID model evaluation of utilization rate with the control variable of equipment's place of origin

Considering equipment's place of origin as a control variable in the DID regression model, Table 7 shows the DID effect value is 3.785 corresponding to p= .000< .01 of the t-test, which suggests a significant difference. This signifies a significant DID effect and the role of outsourcing intervention in increasing utilization rate, with an average effect value of 3.785. When compared to the evaluation outcomes of the DID model excluding the control variable, the net effect increases with the inclusion of the equipment's place of origin as a control variable (t=3.785, p< .001). Therefore, the result underscores the practical importance of the control variable, the equipment's place of origin, in assessing the utilization rate. More imported equipment correlates with a

potentially stronger impact of medical equipment management outsourcing on the utilization rate.

5.1.3 Satisfaction effect evaluation

The DID effect of medical equipment management outsourcing on satisfaction is as follows (Tables 8 and 9):

Table 8 T-test

Item	Control	Treated	Diff	t	p
Satisfaction (Before)	93.112	93.410	.298	1.729	.084
Satisfaction (After)	93.629	95.022	1.394	7.894	.000***

Table 9 Regression Results of the Impact of Medical Equipment Management Outsourcing on Satisfaction

	(1)	(2)	(3)	(4)
VARIABLES	Y	Y	Y	Y
Post	.517***	.517***	.517***	.517***
	(3.107)	(3.664)	(5.262)	(3.866)
Treat	.298*	.751***	.739***	.822***
	(1.718)	(5.062)	(4.952)	(5.808)
Post×Treat	1.096***	1.096***	1.096***	1.096***
	(4.462)	(5.263)	(5.262)	(5.553)
Unit price		-2.743***	-3.012***	-.731*
		(-24.626)	(-7.924)	(-1.831)
Service life			.288	.243
			(.742)	(.660)
Place of origin				-2.541***
				(-13.282)
Constant term	93.112***	93.830***	93.835***	94.089***
	(791.760)	(903.191)	(901.418)	(936.369)
Observations	1552	3104	4656	620
R-squared	.081	.340	.340	.408
p	.000***	.000***	.000***	.000***

Note: ***, **, and * indicate that variables are significant at the significance levels of .01, .05, and .1 respectively. The value in parentheses is t, and Y is the explained variable, representing equipment performance.

1. DID model evaluation of clinical satisfaction without control variables

Table 8 indicates that before the intervention, the DID effect value of the treated and control groups corresponds to p= .084> .05 of the t-test, which suggests no significant difference. This finding implies that before the experiment, no notable difference in effect level existed between the treated and control groups, indicating adherence to the parallel trend assumption by the samples.

Table 8 indicates that after the intervention, the DID effect value of the treated and control groups corresponds to p= .000< .05 of the t-test, which suggests a significant difference. This finding implies that the effect value of the treated group is significantly higher than that of the control group.

Table 9 shows that the DID effect value is 4.462 corresponding to p= .000< .01 of the t-test, which suggests a significant difference. This signifies a significant DID effect and the role of medical equipment management outsourcing intervention in improving clinical satisfaction, with an average effect value of 4.462.

2. DID model evaluation of clinical satisfaction with the control variable of equipment unit price

Considering equipment unit price as a control variable, Table 9 shows that the DID effect value is 5.263 corresponding to p= .000< .01 of the t-test, which suggests a significant difference. This signifies a significant DID effect and the role of outsourcing intervention in improving clinical satisfaction, with an average effect value of 5.263. When compared to the evaluation outcomes of the DID model excluding the control variable (t=4.462, p< .001), the net effect increases with the inclusion of the unit price as a control variable (t=5.263,

p< .001). Therefore, the result underscores the practical importance of the control variable, equipment unit price, in assessing clinical satisfaction. A higher unit price correlates with a potentially stronger impact of medical equipment management outsourcing on clinical satisfaction.

3. DID model evaluation of clinical satisfaction with the control variable of equipment service life

Considering equipment service life as a control variable, Table 9 shows that the DID effect value is 5.262 corresponding to p= .000< .01 of the t-test, which suggests a significant difference. When compared to the evaluation outcomes of the DID model excluding the control variable of service life, the net effect slightly decreases with the inclusion of the control variable (t=5.262, p< .001). The finding implies that longer equipment service life correlates with a potentially slighter impact of medical equipment management outsourcing on clinical satisfaction.

4. DID model evaluation of clinical satisfaction with the control variable of equipment's place of origin

Considering equipment place of origin as a control variable, Table 9 shows that the DID effect value is 5.553 corresponding to p= .000< .01 of the t-test, which suggests a significant difference. This signifies a significant DID effect and the role of outsourcing intervention in improving clinical satisfaction, with an average effect value of 5.553. The net effect increases with the inclusion of the place of origin as a control variable (t=5.553, p< .001). Therefore, the result underscores the practical importance of the control variable, the equipment's place of origin, in assessing clinical satisfaction. More imported equipment correlates with a potentially stronger impact of medical equipment management

outsourcing on clinical satisfaction.

5.1.4 Robustness testing

To verify the robustness of the regression results discussed above, this study selected data from Hospital A and Hospital B before policy intervention for a differential comparison. The assumed date for outsourcing intervention is July 2018, delineating the before-intervention period (July 2017 to June 2018) and the after-intervention period (July 2018 to June 2019). The corresponding regression results are presented in Tables 10 and 11. Despite assuming a hypothetical policy intervention period, the impact of medical equipment management outsourcing on utilization rate and satisfaction was insignificant. Consequently, this study's DID model regression results are validated as robust.

Table 10 DID Model Regression Results (Utilization Rate)

Time	Item	Utilization rate of equipment	Standard error	t	p
Before	Control	5.555	-	-	-
	Treated	6.081	-	-	-
	Diff	.527	.052	10.125	.000***
After	Control	5.207	-	-	-
	Treated	5.756	-	-	-
	Diff	.548	.052	10.544	.000***
Diff-in-Diff	Diff-in-Diff	.022	.074	.296	.767

Table 11 DID Model Regression Results (Satisfaction)

Time	Item	Satisfaction	Standard error	t	p
Before	Control	93.255	-	-	-
	Treated	93.809	-	-	-
	Diff	.554	.167	3.327	.001***
After	Control	94.062	-	-	-
	Treated	94.289	-	-	-
	Diff	.227	.167	1.365	.172
Diff-in-Diff	Diff-in-Diff	-.327	.236	-1.387	.166

5.2 Empirical Research 2

5.2.1 Descriptive statistical analysis

A total of 300 questionnaires were distributed, of which 288 were retrieved. Among these respondents, 64 exhibited a good understanding of the full life cycle management of medical equipment, 217 had some degree of understanding, and seven lacked understanding. Since data from the seven questionnaires from respondents with no understanding of the full life cycle management of medical equipment holds no reference value for research outcomes, and another three questionnaires contained erroneous or missing information, these 10 questionnaires were considered invalid for this study, resulting in a final tally of 278 valid questionnaires.

Table 12 displays the demographic characteristics of participants. From the perspective of gender, 31% of participants are male and 69% are female. The high percentage of female participants may reflect the larger proportion of medical staff among hospital employees and females among medical staff. The age distribution of participants is concentrated in two age ranges: under 30 years old (comprising 39%) and 30–40 years old (comprising 34%), indicating that the sample population skews towards a younger age demographic. Regarding educational levels, 72% of participants hold a bachelor's degree or above. Those with a high school (including technical secondary school) diploma or below and those with an associate degree account for 5% and 23% respectively. This demographic profile indicates a highly educated participant base that has a certain understanding of medical equipment's full life cycle management. The distribution of participants by departments shows that clinical departments represent the largest proportion at 48%, with medical technology and functional

management departments at 27% and 23% respectively. Overall, the study's samples primarily consist of young to middle-aged highly educated individuals with an understanding of medical equipment's full life cycle management. Hence, the samples align well with the ideal target population for this study.

Table 12 Frequency Analysis of Respondent Demographic Characteristics

Variable	Description	Number of samples	Percentage (%)
Gender	Male	86	31%
	Female	192	69%
Age	30-	108	39%
	31∽40	95	34%
	41∽50	59	21%
	51+	16	6%
Education background	High school (including technical secondary school) diploma or below	15	5%
	Associate degree	64	23%
	Bachelor's degree	157	57%
	Master's degree	38	14%
	Doctor's degree or above	4	1%
Department	Medical technology department	76	27%
	Clinical department	133	48%
	Functional management department	64	23%
	Others	5	2%

5.2.2 Reliability analysis

The coefficient value of α ranges from 0 to 1. The closer the value is to 1, the higher the reliability is. Conversely, the closer it is to 0, the lower the reliability is. A higher α value indicates higher reliability of the questionnaire. A value above .9 is considered excellent, around .8 is good, about .7 is moderate, above .5 is acceptable, and below .5 is deemed unacceptable. The data presented in Table 13 show that Cronbach's α for each variable exceeds .9, suggesting good internal consistency among the variables and high reliability of the scale.

Table 13 Variable Reliability Statistics

Variable	Cronbach's α	Number of items
Full life cycle management of medical equipment	.950	10
Utilization rate of equipment	.941	10
Satisfaction	.945	10

5.2.3 Validity analysis

The KMO test measures the correlation between variables by comparing the magnitude of correlation coefficients among each variable and its counterparts. The closer the KMO value is to 1, the more robust the correlation between the variables is. A KMO value below .5 suggests that the data are not apt for factor analysis. Bartlett's test of sphericity assesses the independence of variables by determining if the sample data deviates from a spherical distribution. If the test results indicate a departure from sphericity, the samples are unsuitable for factor analysis.

It can be seen from Table 14 KMO and Bartlett's Tests for the Scale of Medical Equipment's Full Life Cycle Management that the KMO value is .870, and the P value of Bartlett's test of sphericity is .000, which is less than the significance level of .05. This indicates that items of the full life cycle management scale have a strong correlation and are suitable for further factor analysis and correlation analysis.

Table 14 KMO and Bartlett's Tests for the Scale of Medical Equipment's Full Life Cycle Management

KMO measure of sampling adequacy		.870
Bartlett's test of sphericity	Approximation to chi-square distribution	3,460.871
	Degree of freedom	45
	Significance	.000

The results of Table 15 KMO and Bartlett's Tests for the Utilization Rate

Scale reveal that the KMO value is .942, and Bartlett's test of sphericity has a P value of .000, which falls below the significance threshold of .05. These findings indicate a strong correlation among the items of the utilization rate scale and confirm a spherical distribution of the data, justifying the use of factor analysis and correlation analysis.

Table 15 KMO and Bartlett's Tests for the Utilization Rate Scale

KMO measure of sampling adequacy		.942
Bartlett's test of sphericity	Approximation to chi-square distribution	2,454.602
	Degree of freedom	45
	Significance	.000

The results of Table 16 KMO and Bartlett's Tests for the Satisfaction Scale indicate that the KMO value is .90, signifying a strong correlation among items in the satisfaction scale. Additionally, Bartlett's test of sphericity yields a P value of .000, which is consistent with a spherical distribution of the data, making the scale appropriate for factor analysis and correlation analysis.

Table 16 KMO and Bartlett's Tests for the Satisfaction Scale

KMO measure of sampling adequacy		.908
Bartlett's test of sphericity	Approximation to chi-square distribution	2,406.633
	Degree of freedom	45
	Significance	.000

5.2.4 Correlation analysis

The Pearson correlation coefficient ranges from -1 to 1. A coefficient within this range suggests a correlation between two variables. The closer the absolute value of a coefficient is to 1, the higher the correlation between the two variables is. Table 17 presents the results of the correlation analysis for variables. As evident from these results, Pearson correlation coefficients are close to 1, suggesting a significant positive correlation between medical equipment's full

life cycle management, utilization rate, and satisfaction.

Table 17 Pearson Correlation Coefficient

		Full life cycle	Utilization rate of equipment	Satisfaction
Full life cycle	Correlation	1	.914	.934
	Significance (two-tailed test)		.000	.000
	Number of samples	278	278	278
Utilization rate of equipment	Correlation	.914	1	.937
	Significance (two-tailed test)	.000		.000
	Number of samples	278	278	278
Satisfaction	Correlation	.934	.937	1
	Significance (two-tailed test)	.000	.000	
	Number of samples	278	278	278

5.2.5 Regression analysis

1. Medical equipment's full life cycle management and utilization rate

Table 18 presents the regression analysis results for the relationship between medical equipment's full life cycle management and utilization rate. The results show a significant positive effect ($P < .05$) between the two aspects, confirming that there is a positive correlation between medical equipment's full life cycle management and utilization rate under the outsourcing mode.

Table 18 Relationship between Medical Equipment's Full Life Cycle Management and Utilization Rate

Model	Unstandardized coefficient B	Std. Error	Standardized coefficient Beta	t	Significance
Constant	.599	.097		6.144	.000
Full life cycle	.888	.024	.914	37.422	.000

2. Medical equipment's full life cycle management and satisfaction

Table 19 displays the regression analysis results for the relationship

between medical equipment's full life cycle management and satisfaction. These results reveal a significant positive effect (P < .05), indicating that there is a positive correlation between medical equipment's full life cycle management and satisfaction under the outsourcing mode.

Table 19 Relationship between Medical Equipment's Full Life Cycle Management and Clinical Satisfaction

Model	Unstandardized coefficient B	Std. Error	Standardized coefficient Beta	t	Significance
Constant	-.18	.093		-.195	.846
Full life cycle	.979	.023	.934	43.428	.000

3. Medical equipment's full life cycle management and performance

Table 20 presents the regression analysis results for the relationship between medical equipment's full life cycle management and overall performance. The results highlight a significant positive effect (P < .05), suggesting that there is a positive correlation between medical equipment's full life cycle management and overall performance under the outsourcing mode.

Table 20 Relationship between Medical Equipment's Full Life Cycle Management and Performance

Model	Unstandardized coefficient B	Std. Error	Standardized coefficient Beta	t	Significance
Constant	.290	.084		3.445	.001
Full life cycle	.933	.021	.939	45.482	.000

4. Medical equipment classification's regulating effect on medical equipment's full life cycle management and utilization rate

The independent variable, medical equipment's full life cycle management, and the moderating variable, medical equipment classification management, are treated independently and multiplied to obtain an interaction term. The SPSS software and a stepwise regression method were used to include the independent

variable, moderating variable, and interaction term. Table 21 displays the regression analysis results for the regulating effect of medical equipment classification management, with the interaction term result being significant (P < .05). The results indicate that medical equipment classification exerts a positive regulating effect on medical equipment's full life cycle management and utilization rate under the outsourcing mode.

Table 21 Regulating Effect of Medical Equipment Classification Management (Utilization Rate)

Model	Unstandardized coefficient B	Std. Error	Standardized coefficient Beta	t	Significance
Constant	.977	.103		9.524	.000
Full life cycle	.501	.041	.504	12.087	.000
Equipment classification	.307	.411	.411	10.861	.000
Interaction term	-.097	-.123	-.123	-5.759	.000

5. Medical equipment classification's regulating effect on medical equipment's full life cycle management and satisfaction

The SPSS software and a stepwise regression method were used to include the independent variable, moderating variable, and interaction term. Table 22 presents the regression analysis results for the regulating effect of equipment classification on satisfaction, with the interaction term result being insignificant (P = .071). The results show that medical equipment classification does not have a significant regulating effect on medical equipment's full life cycle management and satisfaction.

Table 22 Regulating Effect of Medical Equipment Classification Management (Satisfaction)

Model	Unstandardized coefficient B	Std. Error	Standardized coefficient Beta	t	Significance
Constant	.298	.209		1.427	.000
Full life cycle	.918	.023	.924	40.393	.000
Equipment classification	.017	.077	.005	.225	.822
Interaction term	.140	.77	.046	1.811	.071

6. Medical equipment classification's regulating effect on medical equipment's full life cycle management and performance

The SPSS software and a stepwise regression method were used to include the independent variable, moderating variable, and interaction term. Table 23 depicts the regression analysis results for the regulating effect of equipment classification on overall performance, with the interaction term result being significant ($P < .05$). The results demonstrate that medical equipment classification has a positive regulating effect on medical equipment's full life cycle management and performance.

Table 23 Regulating Effect of Medical Equipment Classification Management (Performance)

Model	Unstandardized coefficient B	Std. Error	Standardized coefficient Beta	t	Significance
Constant	2.855	.204		14.027	.000
Full life cycle	.488	.037	.491	13.133	.000
Equipment classification	-.375	.030	-.463	-12.456	.000
Interaction term	.036	.14	.53	2.505	.013

5.3 Summary of Results

Empirical Research 1 and Empirical Research 2 examine the hypothesized

relationship between variables, obtaining numerical evidence for the relationship between medical equipment management outsourcing (full life cycle management) and performance through data processing and analysis. The test results for research hypotheses are summarized as follows (see Table 24):

Table 24 Summary of Hypothesis Test Results

S/N	Topic	Result	Testing
H1	Medical equipment management outsourcing (full life cycle management) correlates positively with performance.	Valid	Empirical Research 2
H1a	Medical equipment management outsourcing (full life cycle management) correlates positively with financial performance.	Valid	Empirical Research 1, Empirical Research 2
H1b	Medical equipment management outsourcing (full life cycle management) correlates positively with non-financial performance.	Valid	Empirical Research 1, Empirical Research 2
H2	Medical equipment categories exert a positive regulating effect on medical equipment management outsourcing (full life cycle management) and performance.	Valid	Empirical Research 2
H2a	Medical equipment categories exert a positive regulating effect on medical equipment management outsourcing (full life cycle management) and financial performance.	Valid	Empirical Research 2
H2b	Medical equipment categories exert a positive regulating effect on medical equipment management outsourcing (full life cycle management) and non-financial performance.	Invalid	Empirical Research 2

Chapter VI Conclusion

High-end service outsourcing represents a complex issue at the forefront of academic study, with applications in IT, biomedicine, scientific research instrumentation, educational consulting, manufacturing design, finance, and other sectors. It can catalyze process innovation and performance enhancement for outsourcers, while also facilitating business models and technological innovation for contractors. The advancement of public service outsourcing and the maturity of the high-end service industry help integrate high-quality resources, optimize resource allocation, and enhance social efficiency as well as innovation ability. Drawing on the literature reviewed and the results of empirical analysis, this chapter summarizes the research conclusions, proposes countermeasures, and discusses this study's limitations as well as future research.

6.1 Research Conclusions

This study focuses on medical equipment management outsourcing based on the full life cycle management mode. It involves the formulation of hypotheses, mode construction, variable measurement, and data analysis, utilizing various empirical methods to test the proposed relationship model between medical equipment management outsourcing and performance. The results of the data analysis confirm medical equipment management outsourcing's influence on performance and medical equipment categories' regulating effect. The main research conclusions are as follows:

Conclusion 1: medical equipment management outsourcing (full life cycle management) and performance

Empirical research on the relationship between service outsourcing and

performance remains limited. Drawing upon the theoretical framework pertaining to outsourcing-performance dynamics, prior studies have generally yielded three disparate outcomes: a positive correlation, an absence of significant impact, and a negative correlation. Numerous scholars have studied the positive correlation between the enterprise's non-core business outsourcing and performance, as well as between comprehensive equipment management and performance. Smith et al. (2013) found no correlation between medical equipment's full life cycle management and performance in existing studies. Moreover, Cruz and Rincon (2012) believed that empirical research on medical equipment management outsourcing is still in its infancy, with studies focusing on cross-sectional data. Employing an interdisciplinary approach, this study contributes more empirical evidence to outsourcing research in industry segments and public service outsourcing research by integrating theoretical frameworks of outsourcing and performance as well as comprehensive equipment management and performance.

The findings of the study reveal a positive correlation between medical equipment management outsourcing (full life cycle management) and performance. The adage that "every profession requires specialized skills" holds true in this context. The study has confirmed that the outsourcing of medical equipment management services, being the non-core business of hospitals, can enhance the overall performance of medical equipment and provide reliable support for hospitals' core diagnostic and treatment business. Empirical Research 1 employed the DID model to validate Hypotheses H1a and H1b by using panel data from samples. The findings indicate that public hospitals engaging in medical equipment management outsourcing and implementing the

full life cycle management mode can significantly enhance equipment utilization rate and clinical satisfaction, as well as improve equipment's financial and non-financial performance. Furthermore, the impact of medical equipment management outsourcing on equipment utilization rate is more pronounced for medical equipment with higher unit prices, longer service lives, and a higher proportion of imported units. Similarly, medical equipment management outsourcing' effect on clinical satisfaction is more significant for medical equipment with higher unit prices and a higher proportion of imported units. However, medical equipment management outsourcing's impact on clinical satisfaction may diminish as the equipment ages. Empirical Research 2 verified Hypotheses H1, H1a, and H1b through analysis of cross-sectional data based on the questionnaire survey method. The study concludes that medical equipment management outsourcing markedly increases equipment utilization rate and clinical satisfaction. Moreover, it enhances the equipment's financial and non-financial performance and boosts the equipment's overall performance.

Conclusion 2: regulating effect of medical equipment categories

Gilley and Rasheed (2000) incorporated environmental dynamics and enterprise strategy as moderating variables into the empirical analysis of the relationship between enterprise outsourcing and performance. Empirical research on medical equipment management outsourcing is limited, and there appears to be no evidence demonstrating the regulating effect of medical equipment categories. Nevertheless, scholars such as Gao and Zhang (2017) and Liu et al. (2019) suggested that medical equipment classification management can exert a significant positive effect on performance.

In this study's model, the medical equipment category was adopted as a

moderating variable. However, the findings from Empirical Research 2, which utilized a questionnaire survey method, validate H2 and H2a hypotheses but do not support H2b. Specifically, the data suggests that for public hospitals applying the medical equipment management outsourcing mode, the medical equipment category has a positive regulating effect on full life cycle management and financial performance. Nonetheless, there is no regulating effect of the medical equipment category on full life cycle management and non-financial performance. Additionally, the medical equipment category exerts a positive regulating effect on full life cycle management and overall performance. The study's findings reveal that prioritizing large-scale, high-risk medical equipment can enhance both the financial and overall performance of such apparatus. Fundamental to clinical diagnostic and treatment services, it is essential to guarantee the safe and efficient functioning of all medical equipment within the hospital.

6.2 Research Implications and Countermeasures

6.2.1 Implications for medical equipment management outsourcing in Chinese public hospitals

1. Implement scientific and reasonable medical equipment management outsourcing

The Guidance on Strengthening the Operation and Management of Public Hospitals (2020) elevated the importance of operational and management improvement in public hospitals to an unprecedented level. Moreover, the *Opinions on Promoting High-quality Development of Public Hospitals* (2021) explicitly stated that public hospitals should shift their development focus from expanding scales to enhancing quality and efficiency. This study confirms a

positive relationship between the outsourcing of medical equipment management services and the performance of public hospitals in China. It illustrates a progression from exploratory attempts – metaphorically described as "seeking the way" and "throwing stones to ask the way" – to following a well-defined path. Given China's current national conditions, the study suggests that it is a viable solution for public hospitals to address their challenges and pain points by strategically adopting outsourced medical equipment management services, along with comprehensive life cycle management practices. Given existing national laws and regulations, public hospitals can make informed outsourcing decisions based on their specific circumstances. Factors to be considered include the scale, category, and grade of medical equipment; the quantity, expertise, and management skills of professionals; operation and maintenance costs; and operational efficiency. Public hospitals should make decisions by prioritizing clinical diagnostic and treatment needs based on their management and development strategies.

In recent years, some domestic public hospitals have emerged as pioneers in outsourcing and maximized the overall benefits derived from medical equipment by making breakthroughs in traditional operational models and overcoming institutional and talent constraints. Industry experts have proposed viable perspectives on the trend toward widespread provision of after-sales services for medical equipment. Nevertheless, medical equipment management outsourcing, a strategic decision in hospital operations and management, faces several challenges in widespread implementation. These include reallocating hospitals' existing staff, avoiding third-party technological monopolies, and ensuring accountability of third-party enterprises. This study focuses on the

outsourcing of comprehensive medical equipment management services. Hospitals may consider outsourcing some of these services based on their management needs or adopting selective outsourcing that excludes spare parts and consumables. This approach warrants further exploration.

2. Enhance full life cycle management of medical equipment

An adage goes, “For a craftsman, if he wants to do his job well, he must first sharpen the tools he uses.” Based on existing studies, the implementation of medical equipment’s full life cycle management is a “sharp tool” for enhancing equipment performance. This study validates that implementing refined management across all stages of medical equipment’s full life cycle has a positive effect on performance. The difference is that the research subjects have adopted a management outsourcing mode. The questionnaire of Empirical Research 2 surveyed all potential participants in the hospital. Although Hospital A has engaged in medical equipment management outsourcing and implemented full life cycle management for over four years, the gathered questionnaires reveal that only 22% of the respondents are well-informed about full life cycle management, while 2% do not know it at all. Hence, hospitals that opt for medical equipment management outsourcing should consider the following aspects: First, as the full life cycle management of medical equipment constitutes a systematic project, it is essential to incorporate the concept of full life cycle management into the minds of all hospital staff. Second, medical equipment management should not be the sole responsibility of the medical engineering department but also entails collaboration with diagnostic, treatment, and administrative departments. Enhancing the full life cycle management of medical equipment under the outsourcing mode requires not only vigorous

advocacy by hospital management but also effective coordination among different departments and third-party teams. The design of a full life cycle management system for medical equipment should comply with national regulations and primarily address the needs of clinical diagnosis and treatment. The goal is to enhance clinical satisfaction and build a secure and efficient healthcare environment.

3. Establish a performance-oriented full life cycle management information system for medical equipment

The development of a performance-oriented full life cycle management information system for medical equipment provides essential support for achieving full life cycle management of medical equipment and serves as a critical foundation for enhancing the quality of full life cycle management. As hospitals advance “business-finance integration,” it is imperative to develop a management information system that covers the full life cycle from application and procurement to usage and scrapping. This system should be integrated with systems such as PACS, HIS, LIS, and WMS to establish a data-integrated ecological platform. The objective is to break down data silos and eliminate the “island effect,” thus truly achieving full life cycle closed-loop management of medical equipment.

4. Select capable outsourcers

Partnering with capable outsourcers is critical for hospitals to attain the desired performance and enhance the success rate of medical equipment management outsourcing. In outsourcer selection, it is necessary to consider their scale, qualifications, technology, and team as well as their abilities in full life cycle management, performance analysis, and historical performance

records. Drafting an outsourcing contract needs to specify the scope of services, maintenance benchmarks, performance metrics, service fees, and default penalties. Furthermore, hospitals should conduct strict supervision and management throughout the outsourcing process following the contract.

6.2.2 Implications for third-party enterprises

Third-party enterprises can leverage the integrated data platform that covers the full life cycle management of medical equipment to summarize critical management factors, underpin management decisions, and constantly refine management in each link. They can automatically grab data in key links, facilitate performance analyses that transform from focusing on individual pieces of medical equipment to covering the whole hospital's inventory, and continuously enhance the equipment's financial and non-financial performance. Enabled by IoT technologies like 5G and RFID, real-time, dynamic, and remote management become feasible, improving the allocation of medical equipment resources.

6.2.3 Policy suggestions on enhancing medical equipment management

1. Formulate industry standards for after-sales services of medical equipment

Amidst an aging population and the post-pandemic era, China's medical equipment market is growing steadily as new hospital infrastructure construction and domestic production of equipment progress. In the U.S., for example, the maintenance costs in the middle and later stages of the medical equipment's full life cycle account for about 80% of the total expenses, far surpassing initial procurement costs. However, there are no unified industry standards for the after-sales services in the middle and later stages of the medical

equipment's full life cycle in China. Empirical Research 2 found no evidence to support the regulating effect of medical equipment management risk categories on outsourcing and satisfaction, which indicates that safety and quality remain paramount regardless of the medical equipment category. Optimizing industry standards, policies, and regulations for after-sales services of medical equipment and establishing a comprehensive quality control management system can help illuminate blind spots in management and ensure medical equipment's safe and effective operation.

2. Develop and refine the certification system for clinical medical engineers

Medical equipment is essential for medical institutions to provide diagnostic and treatment services. Grade-3 hospitals operate the most advanced equipment and attract the most clinical medical engineers, resulting in a significant shortage of clinical medical engineers in primary medical institutions. In this study, Hospital A serves as the medical community's leading unit and the medical alliance's member unit. The medical community underscores the importance of "community" to facilitate the provision of medical services to all households, strengthen the community's construction, and ensure that underlying diseases are diagnosed and treated effectively. The medical alliance stresses "alliance," aiming to offer comprehensive medical services, advance the alliance's development, and ensure that complicated diseases are properly treated. It is necessary to promptly establish a complete certification system for clinical medical engineers, develop an evaluation mechanism for the professional titles of third-party resident medical engineers, and institute a multi-site medical practice mechanism and a remuneration

system for clinical medical engineers. This will facilitate the decentralization of high-quality medical engineering resources, help achieve uniform medical equipment management, and address the issue that supply falls short of demand in medical services.

3. Discipline construction and talent cultivation

The technical sophistication of medical equipment is surpassed only by that of the aerospace industry. Given the quick upgrading of medical equipment, it is imperative to prioritize discipline construction and talent cultivation. Moreover, the high-quality development of medical equipment management cannot be achieved without skilled professionals. Talent teams are crucial for implementing full life cycle management of medical equipment and achieving cost reduction and efficiency improvement. At present, biomedical engineering programs in universities and colleges tend to be research-centric, while there is a shortage of practical and interdisciplinary talent in front-line medical engineering departments. University and college students with strong theoretical backgrounds need to immerse themselves in clinical practices, participate in vocational skills training, and integrate into the clinical engineering system to truly meet the talent requirements of medical institutions. Most medical engineers without higher education credentials were trained in an apprenticeship model that emphasizes hands-on maintenance and are in greater need of theoretical training and continuing education. Only by vigorously enhancing discipline construction, comprehensively improving the overall quality and abilities of clinical medical personnel, and fostering enterprise-university-research institute integration, can we advance the sustainable development of medical and healthcare services.

6.3 Research Limitations and Shortcomings

This study is constrained by the author's academic abilities and many practical factors, such as the innovativeness of management mode, the uniqueness of medical services, and the attributes of asset operation data. Besides, certain phases of the study were undertaken during the pandemic. Based on research objectives set in the initial stage, theoretical discussion, field research, and empirical analyses have yielded several empirical results and research findings. Nonetheless, this study has limitations and shortcomings in the following areas:

1. Research subjects

This study only selected medical equipment from public hospitals in China. However, China still has a large number of private hospitals—different from public hospitals in terms of attributes—which serve as important supplements to the public hospitals in China's healthcare system. Categorized by scale, there are many primary medical institutions such as community health service centers, which are the robust foundation for advancing the tiered diagnosis and treatment system. The varying attributes and scales of medical and health institutions may have different effects on the relationship between medical equipment management outsourcing and performance.

Besides, the industry characteristics and differences in countries of management outsourcing may impact the universality of research conclusions. On the one hand, medical and health services and the medical equipment management system in China are quite different from those in developed regions such as Europe and the U.S. The differences in national conditions and environments possibly lead to significantly different results in the relationship

between medical equipment management outsourcing and performance. On the other hand, even regarding the same aspect of medical equipment management outsourcing, significant disparities may exist between the healthcare sector and other industries in terms of industry characteristics, market environment, and spare parts supply chain management. Consequently, the analytical conclusions of this study have limitations, and the applicability of these findings to equipment management in other sectors requires further validation through research.

2. Hypotheses and verification

This study's hypotheses identified 10 key links in management outsourcing from the perspective of the full life cycle management of medical equipment, forming specific connotations of the independent variable. Nevertheless, various key factors in the full life cycle may not be considered. The empirical research selected only the equipment utilization rate and clinical satisfaction as indicators for financial and non-financial performance measurement, with the equipment management risk category introduced as the moderating variable. Hence, the test results may not be comprehensive enough. Furthermore, as the empirical analysis did not conduct an individual evaluation of the key elements of full life cycle management and performance indicators, the test results may not be accurate enough. In addition, medical equipment is at different stages of its life cycle, located in various departments and hospital campuses, and has different resource allocations. Outsourcing management services corresponding to each dimension may potentially bring about different impacts, which have not been taken into consideration yet.

3. Research methods

Shen et al. (2015) believed that for the DID model to effectively evaluate an intervention's effect, three hypotheses must be satisfied in addition to the prerequisite of linear regression: First, the intervention should not influence the control group; second, all factors apart from the intervention must equally affect intervention and control groups; third, certain characteristics of the observational units in intervention and control groups must remain consistent. Beginning with the building of the DID model, two essential criteria must be met for its application: First, there must be an external impact with the pilot nature that allows for the differentiation between the intervention group and the control group; second, panel data sets spanning at least two years (including the year before and the year after the intervention) are required.

According to the aforementioned criteria, Empirical Research 1 employed the DID model to investigate the net effect of the performance of medical equipment management outsourcing. This approach basically aligns with the assumed conditions for the DID model. However, upon comparison with the preconditions of the classical model, there are some minor deviations in key conditions. Firstly, policy impacts do not correspond to a single point in time. The occurrence of medical equipment management outsourcing is usually a result of multiple policies being issued and combined with other comprehensive factors. Second, medical equipment management outsourcing in public hospitals is essentially a form of public service outsourcing, necessitating budget management and government procurement. Outsourcing is often conducted over a period of time rather than instantaneously. Third, although medical equipment management outsourcing in Hospital A carries an external impact with the pilot nature, it may have endogeneity problems. Overall, the

DID model's application in medical equipment management is not well-established. As an exploratory research method, the model does not fully conform to the application conditions of standard models and may possess limitations and shortcomings.

4. Data

Regarding the quantity of research data: Hospitals have a large number of medical equipment items and diverse categories. The number of hospitals that have implemented comprehensive medical equipment management outsourcing and meet the research criteria is limited. The sample data were derived solely from Hospital A (implemented outsourcing) and Hospital B (did not implement outsourcing) and did not encompass a large-scale sample that includes hospitals at different levels, in various regions, and with distinct attributes. The limited scope of the sample data may compromise the study's external validity.

Regarding the quality of research data: Some of the variable measurement indicators have taken into account the results of previous studies and field research, and the validity of these indicators requires corroboration through studies. In Empirical Research 1, the classification of original data by equipment name revealed disparities in equipment's unit price, service life, and place of origin in the same sample, which may affect the sample data's quality. The questionnaire design for Empirical Research 2 quantified the selected elements as objectively as possible. Nonetheless, due to professional research topics and significant differences among respondents, quantifying some elements was challenging. Hence, there will be some subjective biases in the questionnaire data.

6.4 Expectations for Future Research

Given China's national conditions and policy environment, this study endeavors to delve into interdisciplinary domains. However, constrained by my academic abilities and objective circumstances, this study is more akin to "tentative research." With the advent of digital operations, refined management, and standardized data in medical services, empirical research into operation and maintenance management in the field of medical engineering will develop rapidly. This study aims to provide reference for future studies based on its discussion of methodologies:

1. With sample data drawn from Chinese public hospitals, this study focuses on medical equipment management outsourcing, yielding preliminary conclusions. However, whether these results apply to Chinese private hospitals, Chinese primary medical institutions, or medical and health institutions in other countries, as well as whether they are applicable in equipment management outsourcing in other sectors, such as scientific research equipment, office equipment, and industrial equipment, remain subject to debate and further research regarding the research results' universality.

2. Based on the medical equipment management service information platform, this study constructed a relationship model between medical equipment management outsourcing and performance through the lens of full life cycle management. Choices made in hypothesis selection, variable measurement, model building, and research methodologies can have varying effects on financial and non-financial performance. These aspects merit exploration and validation in future studies.

3. Panel data from the intervention and control groups in Empirical

Research 1 were collected in the year before and after the commencement of the outsourcing intervention. However, tracking the full life cycle of each piece of medical equipment requires a longer observation period. If continuous tracking of research subjects is possible, with panel data covering the entire life cycle, empirical results can be more rigorous and precise, leading to research conclusions that hold greater practical significance.

4. In this study, campuses of Hospital A and Hospital B are under unified management. The medical equipment across these hospital campuses can be regarded as a platform for sharing resources in a small sample framework. If there were larger sample sizes available for research in the future, analyzing from three platform dimensions—medical equipment asset management, medical equipment spare parts management, and management service engineer—could lead to more forward-looking and innovative studies.

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Appendix

Questionnaire for Full Life Cycle Management of Medical Equipment

Dear respondents,

Hello! Thank you for taking time out of your busy schedules to answer the questionnaire for the Zhejiang University Entrepreneur Fellows Program. This study aims to understand the impact of full life cycle management on performance after your hospital has implemented medical equipment management outsourcing to facilitate your hospital's high-quality development. The questionnaire is designed to be completed anonymously and your responses will be invaluable to the study. All information will be kept strictly confidential and used for research purposes only. Please answer the questions based on the actual situation of medical equipment management in your hospital. Completing the questionnaire takes just a few minutes. Please respond to all questions sequentially without omission. We appreciate your support and attention!

[Part I: Basic Personal Information]

1. Gender: □Male □ Female

2. Age: □30 or below □ 31-40 □ 41-50 □ 51 or above

3. Education background: □High school (including technical secondary school) diploma or below □ Associate degree □ Bachelor's degree □ Master's degree □ Doctor's degree or above

4. Department: □Medical technology department □ Clinical department □ Functional management department □ Others

5. Full life cycle management of medical equipment encompasses a closed-loop management system that covers medical equipment's full life cycle and focuses

on the equipment's safe operation. Are you familiar with the full life cycle management of medical equipment in your hospital?

□ Very familiar □ Understand □ Unfamiliar

[Part II: Full Life Cycle Management of Medical Equipment]

Please select the corresponding score and mark it with a "√" based on the implementation of each major link in medical equipment's full life cycle management in your hospital and department.

Full life cycle management of medical equipment (low-high)	Poor	Relatively poor	Moderate	Relatively good	Good
Asset inventory	1	2	3	4	5
Installation review and acceptance	1	2	3	4	5
Preventative maintenance	1	2	3	4	5
Routine inspection	1	2	3	4	5
Training	1	2	3	4	5
Measurement	1	2	3	4	5
Testing	1	2	3	4	5
Maintenance	1	2	3	4	5
Quality control	1	2	3	4	5
Scrapping	1	2	3	4	5

[Part III: Utilization Rate]

Based on the actual situation in your hospital and department, please select the corresponding score and mark it with a "√" to indicate the impact of full life cycle management of medical equipment on enhancing the utilization rate.

Utilization rate enhancement (low-high)	Very insignificant	Insignificant	Moderate	Significant	Very significant
Asset inventory	1	2	3	4	5
Installation review and acceptance	1	2	3	4	5
Preventative maintenance	1	2	3	4	5
Routine inspection	1	2	3	4	5
Training	1	2	3	4	5
Measurement	1	2	3	4	5
Testing	1	2	3	4	5
Maintenance	1	2	3	4	5
Quality control	1	2	3	4	5
Scrapping	1	2	3	4	5

[Part IV: Satisfaction]

Based on the actual situation in your hospital and department, please select the corresponding score and mark it with a "√" to indicate the impact of full life cycle management of medical equipment on improving clinical satisfaction.

Satisfaction improvement (low-high)	Very insignificant	Insignificant	Moderate	Significant	Very significant
Asset inventory	1	2	3	4	5
Installation review and acceptance	1	2	3	4	5
Preventative maintenance	1	2	3	4	5
Routine inspection	1	2	3	4	5
Training	1	2	3	4	5
Measurement	1	2	3	4	5
Testing	1	2	3	4	5
Maintenance	1	2	3	4	5
Quality control	1	2	3	4	5
Scrapping	1	2	3	4	5

[Part V: Classification Management of Medical Equipment]

Per the *Regulations on the Supervision and Administration of Medical Devices (2021)*, medical devices are categorized into three groups based on varying levels of management risks: Category I denotes devices with low risk, requiring routine management for safety and effectiveness; Category II signifies moderate-risk devices requiring stringent control and management to ensure safety and effectiveness; Category III encompasses high-risk devices necessitating special measures for strict control and management to guarantee safety and effectiveness. Based on the actual situation in your hospital and department, please select the corresponding score and mark it with a "√" to indicate the impact of full life cycle management on enhancing equipment performance, after medical equipment has been categorized by levels of

management risks.

Utilization rate enhancement	Very insignificant	Insignificant	Moderate	Significant	Very significant
Category I	1	2	3	4	5
Category II	1	2	3	4	5
Category III	1	2	3	4	5

Satisfaction improvement	Very insignificant	Insignificant	Moderate	Significant	Very significant
Category I	1	2	3	4	5
Category II	1	2	3	4	5
Category III	1	2	3	4	5

Thanks again for your support and cooperation! Wishing you the very best in your work!