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The Construction and Implementation of the Comprehensive Management and Control System for Facilities and Equipment in Property Services

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Abstract: This paper delves into the comprehensive management and control system for property service facilities and equipment. It expounds on the importance of this system, analyzes limitations of traditional methods, and details its integration of multiple aspects, design principles, core functional modules, and phased implementation. It also explores the role of IoT, big data, and digital twin technologies, and addresses challenges like multi-system integration, staff training. Case studies demonstrate its effectiveness, and future research directions are proposed.

Keywords: Property service; Facilities and equipment management; Comprehensive management and control system

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1. Introduction

In the field of property services, the efficient management of facilities and equipment is crucial. With the continuous development of urbanization and the increasing complexity of property types, traditional management methods are facing limitations. In response, the construction and implementation of a scientific and advanced comprehensive management and control system for facilities and equipment have become an urgent need. The Chinese government issued the "Property Service Industry Standardization Promotion Plan (2023–2025)" in 2023, aiming to standardize the property service industry, which provides policy support for the construction of this system. This system integrates multiple aspects, involving principles like intelligence, automation, and standardization, and includes key functional modules. Its implementation process, as well as the integration of technologies such as IoT and big data, are of great significance for improving the utilization rate of facilities and equipment, extending their lifespan, and promoting the healthy development of the property service industry. In particular, the intelligent facility management system based on IoT and digital twin technology proposed by Chen *et al.* provides an important technical reference for achieving intelligent and automated facility management [1].

2. Key elements of comprehensive management system construction

2.1. Design principles of facilities management system

The design principles of the facilities management system in property services play a crucial role in achieving effective and efficient management. Intelligence is one fundamental principle. With the development of technology, intelligent systems can collect real-time data on facilities, such as energy consumption, operating status, and maintenance needs. For example, smart sensors can monitor the temperature and humidity of a building's interior environment, and automatically adjust relevant equipment, like air-conditioners, to optimize energy use and user comfort [2].

Automation is another key principle. Automated systems can streamline many routine tasks, reducing human error and labor costs. Automated equipment can perform functions such as regular inspections, fault diagnosis, and even some simple repair tasks. For instance, automated cleaning robots can clean floors in large-scale commercial properties at fixed times, ensuring a clean environment without the need for continuous human supervision.

Standardization is also essential. Standardized design ensures that all facilities in property services follow a unified set of rules and procedures. This includes standardizing equipment specifications, maintenance processes, and safety requirements. By doing so, it becomes easier to manage different types of facilities, train maintenance personnel, and ensure seamless integration of new facilities into the existing management system. These three principles, intelligence, automation, and standardization, are inter-related and jointly contribute to the full-lifecycle management of property service facilities.

2.2. Core functional modules in equipment control systems

In the equipment control systems within the comprehensive management and control system for facilities and equipment in property services, several key functional modules play crucial roles. Asset registration is fundamental. It involves accurately recording detailed information of each piece of equipment, including its type, model, purchase date, location, and ownership. This provides a clear inventory base for subsequent management [3]. Maintenance scheduling aims to ensure the normal operation of equipment. By formulating scientific and reasonable maintenance plans according to the equipment's usage frequency, service life, and performance requirements, regular inspections, repairs, and component replacements can be carried out in a timely manner, thus extending the equipment's lifespan and reducing the risk of breakdowns. Energy consumption monitoring is an important aspect. Through real-time monitoring of equipment energy consumption data, property managers can identify energy-wasting equipment or operation modes, and then take corresponding improvement measures to achieve energy-saving goals. Furthermore, the emergency response mechanism is essential for dealing with unexpected equipment failures. It should include pre-established emergency plans, a team of trained emergency response personnel, and necessary emergency repair resources. When an emergency occurs, a rapid response can be initiated to minimize the impact on property services and users. These core functional modules work in coordination to ensure the efficient operation and effective management of the equipment control systems.

3. Implementation framework for integrated control systems

3.1. Strategic planning of phased implementation processes

The phased implementation processes of the integrated control system for facilities and equipment in property services begin with pilot projects. A few representative property service areas were selected to test the initial version of the comprehensive management and control system. This allows for real-world evaluation of system functionality, such as its ability to monitor equipment status accurately and manage facility-related tasks. During this stage, collect feedback from property managers, maintenance staff, and residents to identify any potential issues or areas for improvement [4].

Following the completion of the pilot projects, technical verification is conducted to evaluate the system's performance. Data collected during the pilot phase are analyzed to assess whether the system meets requirements for data accuracy, response time, and operational stability. In collaboration with technical experts, identified issues are addressed through algorithm optimization, system refinement, and enhanced security measures, ensuring that the system is reliable and robust enough for large-scale application.

Subsequently, full-scale deployment is initiated in property service scenarios. After successful technical validation, the comprehensive management and control system is rolled out across all relevant property service areas. Targeted training is provided to property service personnel to ensure proficient system use. During large-scale deployment, continuous monitoring of system operation is carried out, and a long-term maintenance and improvement mechanism is established to accommodate evolving property service demands and ongoing technological advancements.

3.2. Integration of IoT and big data technologies

The integration of IoT and big data technologies plays a pivotal role in the implementation framework of the comprehensive management and control system for facilities and equipment in property services. IoT sensors are deployed throughout the facilities to collect real-time data on various parameters such as equipment status, energy consumption, and environmental conditions. These sensors act as the "eyes and ears" of the system, continuously transmitting a vast amount of raw data [5].

Big data technologies then come into play to process, analyze, and make sense of this massive data flow. Advanced analytics algorithms can identify patterns, trends, and anomalies in the data. For example, by analyzing historical and real-time energy consumption data, predictive analytics can forecast future energy demands, enabling property managers to optimize energy usage.

The combination of IoT and big data also enables more accurate fault prediction for facilities and equipment. If an IoT sensor detects a slight deviation in an equipment's operating parameter, big data analytics can compare this data with historical failure patterns. This early warning system helps property managers schedule maintenance in a timely manner, reducing downtime and prolonging the lifespan of the equipment.

Furthermore, digital twin technology, which is closely related to the integration of IoT and big data, creates a virtual replica of the physical facilities. The IoT-collected data updates the digital twin in real-time, and big data-driven simulations on the digital twin can be used to test different management strategies, ensuring the efficient operation of the comprehensive management and control system.

4. Operational application and case studies

4.1. Optimization effects in property facility management

4.1.1. Efficiency improvement in maintenance operations

Through case studies of HVAC system management, it becomes possible to quantify the reduction in maintenance cycles and cost savings, thereby vividly demonstrating the efficiency improvement in maintenance operations within property facility management. In the case of a large-scale commercial building, before implementing the comprehensive management and control system for facilities and equipment in property services, the HVAC system maintenance was mainly based on a fixed-time schedule. This traditional approach often led to either over-maintenance, where components were serviced prematurely, wasting resources, or under-maintenance, resulting in system failures and higher repair costs.

After the implementation of the new management and control system, real-time monitoring of key HVAC parameters, including temperature, pressure, and energy consumption, was successfully achieved. By leveraging data analytics, the system could accurately predict potential component failures and proactively optimize maintenance schedules. A notable outcome was the data-driven revision of maintenance cycles for specific components, which were safely extended from the original monthly schedule to a quarterly basis, thereby significantly optimizing resource allocation and reducing operational costs.

Consequently, this not only decreased the labor costs associated with frequent maintenance but also minimized the cost of spare parts replacement due to unnecessary over-maintenance. The case study clearly shows that the comprehensive management and control system can effectively improve the efficiency of maintenance operations in property facility management, achieving a win-win situation of reducing maintenance cycles and cost savings [6].

4.1.2. Energy conservation achievements in equipment operation

In the realm of property facility management, remarkable energy conservation achievements can be witnessed in equipment operation. Take smart lighting systems for instance. By leveraging advanced sensor technologies and intelligent control algorithms, these systems can adjust illumination levels based on real-time occupancy and ambient light conditions. In a large-scale commercial property, the installation of such a smart lighting system led to a significant reduction in energy consumption. Sensors detected when areas were unoccupied and automatically dimmed or turned off the lights, saving a substantial amount of electricity.

Elevator management also plays a crucial role in energy conservation. Modern elevator control systems are designed to optimize the operation routes of elevators. For example, in high-rise residential buildings, the system can group elevator calls, allowing elevators to serve multiple floors more efficiently. This not only improves passenger waiting times but also reduces the overall energy consumption of the elevator equipment. Through these operational applications of smart lighting and elevator management in property services, as demonstrated by practical cases, it is evident that significant energy conservation can be achieved in property facility management, contributing to both cost-savings for property owners and environmental sustainability [7].

4.2. Challenges and solutions in system implementation

4.2.1. Technical barriers in multi-system integration

In the construction and implementation of the comprehensive management and control system for facilities and equipment in property services, multi-system integration presents numerous technical barriers. One prominent issue lies in the interface compatibility among security, firefighting, and energy systems.

Security systems often rely on specific communication protocols and data formats to ensure real-time monitoring and quick response to potential threats. Firefighting systems, on the other hand, need to integrate with security systems to trigger alarms and evacuation procedures in case of fire. Energy systems, meanwhile, focus on data collection and management related to energy consumption. However, the differences in these systems' hardware and software architectures can lead to interface incompatibility.

For example, the security system may use a proprietary communication protocol that is not easily recognizable by the firefighting or energy systems. This makes it difficult to share data and achieve seamless interaction among them. To address this, standardization of interfaces is crucial. Adopting international or industry-wide standards can enhance compatibility. Additionally, developing middleware can act as a bridge to translate data formats and communication protocols between different systems. Through these solutions, the multi-system integration can be more effectively realized, promoting the smooth operation of the comprehensive management and control system for property service facilities and equipment [8].

4.2.2. Staff training and organizational adaptation

During the implementation of the comprehensive management and control system for facilities and equipment in property services, staff training and organizational adaptation present significant challenges. Property engineers need to enhance their competencies during the digital transformation. One challenge is that traditional property engineers may lack digital skills. They are accustomed to manual operation and management of facilities and equipment, but the new system requires proficiency in digital tools for real-time monitoring, data analysis, and remote control [9].

To address this, training programs should be designed. These programs should cover digital technology basics, such as the use of IoT sensors, software for facility management, and data analytics platforms. For example, training on how to interpret data from IoT sensors installed on elevators to predict potential malfunctions can improve engineers' ability to manage equipment proactively.

Organizational adaptation is another aspect. The traditional organizational structure in property services may be hierarchical and slow to respond. The new system demands a more flexible and collaborative structure. Departments need to communicate more effectively to ensure a seamless operation of the management and control system. For instance, the engineering department should work closely with the IT department to resolve any technical glitches in the system promptly. To adapt, organizations can restructure teams, encourage cross-departmental communication, and establish a culture that values innovation and digital transformation. This way, both staff and the organization can better adapt to the requirements of the new comprehensive management and control system.

5. Maintenance strategies and system optimization

5.1. Preventive maintenance mechanism design

5.1.1. Predictive maintenance models based on equipment lifespan

Predictive maintenance models based on equipment lifespan play a crucial role in the comprehensive management and control system for facilities and equipment in property services. By establishing mathematical models for critical component replacement timing in electromechanical systems, these models can effectively predict when certain components are likely to fail based on the estimated lifespan of the equipment [10]. This allows property service providers to plan maintenance activities in advance, minimizing unplanned downtime and reducing the risk of sudden equipment breakdowns. The models take into account various factors such as the operating environment, usage frequency, and historical failure data of the equipment. Through sophisticated algorithms and data analysis techniques, they can accurately forecast the remaining useful life of components and the overall equipment. This enables proactive decision-making, ensuring that replacement parts are procured in a timely manner and maintenance teams are deployed efficiently. Overall, predictive maintenance models based on equipment lifespan enhance the reliability and efficiency of the facilities and equipment management in property services, optimizing resource allocation and ultimately improving the quality of service provided to property owners and tenants.

5.1.2. Maintenance strategy classification matrix

A maintenance strategy classification matrix is developed based on two key dimensions: equipment criticality and failure probability. Equipment criticality reflects the potential impact of equipment failure on property service operations, safety, and user experience. High-criticality equipment includes assets such as elevators in residential buildings or power supply systems in commercial properties, where failures may cause severe operational disruptions, safety risks, or substantial economic losses. Failure probability is evaluated through historical failure data, component wear models, and environmental conditions, as certain equipment may exhibit higher failure rates due to intensive usage, harsh operating environments, or component aging.

Based on the combination of these two dimensions, differentiated maintenance strategies can be defined. Equipment with high criticality and high failure probability requires a proactive maintenance strategy, incorporating frequent inspections, predictive maintenance supported by real-time condition monitoring sensors, and shortened replacement cycles for critical components [11]. For equipment with high criticality but low failure probability, a preventive maintenance approach with extended inspection intervals is generally adequate. Assets characterized by low criticality and high failure probability can be managed through a corrective maintenance-oriented strategy, in which repairs are performed after failures occur. Equipment with both low criticality and low failure probability is suited to a minimal-intervention maintenance strategy to optimize resource utilization. This classification matrix offers a systematic framework for allocating maintenance resources efficiently and ensuring the reliable operation of facilities and equipment in property service environments.

5.2. Data-driven optimization approaches

5.2.1. Operational parameter adjustment using machine learning

Machine learning can play a crucial role in adjusting operational parameters for more efficient water pump operations in property service facilities and equipment management. By leveraging real-time data analysis, property managers can gain insights into the performance of water pumps. For example, machine-learning algorithms can analyze data such as water flow rate, pressure, power consumption, and temperature collected from sensors installed on the water pumps [12].

These algorithms can then establish models to predict the optimal operational state of the pumps under different conditions. For instance, during periods of low water demand, the machine-learning model can suggest reducing the pump speed to save energy without compromising the water supply quality. It can also detect anomalies in the pump's operation. If the power consumption suddenly deviates from the normal range predicted by the model, it indicates a potential problem, such as a mechanical failure or a blockage in the pipeline.

Moreover, machine-learning-based operational parameter adjustment is not a one-time task. As the property's water usage patterns change over time, for example, due to seasonal variations or changes in tenant occupancy, the model can continuously learn from new data and adjust the recommended operational parameters accordingly. This dynamic adjustment ensures that the water pump operates at its best performance level, maximizing energy efficiency, extending the equipment's lifespan, and reducing maintenance costs in property service facilities.

5.2.2. Spare parts inventory optimization through usage patterns

Spare parts inventory management is a crucial aspect of property service facilities and equipment management. By leveraging historical maintenance data analytics, significant improvements can be made. Analyzing usage patterns of spare parts provides valuable insights into their consumption trends. For instance, some parts may be used frequently due to high-wear components in certain equipment, while others are rarely needed.

This data-driven approach enables property service providers to optimize inventory levels. If a particular spare part has a stable and high-frequency usage pattern, maintaining a sufficient stock can prevent long-term equipment downtime. On the other hand, for parts with low and irregular usage, over-stocking should be avoided to reduce inventory costs.

Historical data can also reveal seasonal or event-related usage patterns. For example, during the peak cooling season, parts related to air-conditioning systems may see increased consumption. By accurately forecasting these demands based on past data, property managers can plan their inventory procurement more effectively.

In addition, understanding usage patterns helps in identifying obsolete spare parts. If a part has not been used for an extended period and shows no signs of future demand, it can be removed from the inventory, freeing up storage space and capital. Overall, through the analysis of spare parts usage patterns based on historical maintenance data, property service providers can achieve a more efficient and cost-effective spare parts inventory management system [13].

5.3. Continuous improvement cycle implementation

5.3.1. PDCA cycle application in system upgrades

The PDCA cycle, consisting of Plan, Do, Check, and Act, is a powerful tool for enhancing the system upgrades in the comprehensive management and control system for facilities and equipment in property services. In the "Plan" stage, property service providers need to carefully analyze the current status of facilities and equipment management, identify areas for improvement such as inefficiencies in maintenance scheduling or outdated safety protocols. Based on this analysis, detailed plans for system upgrades are formulated, including setting clear goals, defining tasks, and allocating resources [14].

The "Do" stage involves the actual implementation of the upgrade plans. Technicians and relevant staff execute the tasks defined in the plan, such as installing new management software, upgrading equipment components, or training employees on new management procedures. During this process, it is crucial to ensure that the implementation is carried out in strict accordance with the plan.

In the "Check" stage, a comprehensive evaluation of the upgrade results is conducted. Key performance indicators (KPIs) are used to measure whether the upgrade goals have been achieved. For example, check if the equipment downtime has decreased, or if the accuracy of maintenance records has improved. Any discrepancies between the actual results and the planned goals are identified and analyzed.

Ultimately, in the "Act" stage, based on the findings from the "Check" stage, appropriate actions are taken. If problems are detected, corrective measures are implemented, and the upgrade plan may be adjusted accordingly. Successful practices are standardized and incorporated into the regular management system to continuously improve the overall quality of facilities and equipment management in property services.

5.3.2. Benchmarking against industry best practices

To enhance the construction and implementation of the comprehensive management and control system for facilities and equipment in property services, benchmarking against industry best practices is essential as follows:

(1) Identify leading companies in property service facilities and equipment management, either locally or

globally. These could be those renowned for their innovative maintenance strategies, advanced system optimization, or high-quality service delivery. Analyze their operational models, from how they allocate resources for maintenance to the technologies they adopt for system monitoring and control [15];

(2) Study their performance evaluation metrics which are aligned with international facility management standards. Understand how they measure key performance indicators such as equipment uptime, maintenance cost-effectiveness, and customer satisfaction related to facility services. By comparing these metrics with those of the property service in question, areas for improvement can be clearly pinpointed. For example, if a top-performing company has a significantly higher equipment uptime rate, it may be due to their more proactive preventive maintenance schedule or better-trained maintenance staff;

(3) Adapt and integrate the best practices into the existing management and control system. This doesn't mean a wholesale adoption but rather a customized implementation based on the unique characteristics of the property service, including its scale, type of facilities, and customer base. Through this benchmarking process, the property service can continuously refine its maintenance strategies and system optimization, ultimately improving the overall quality of its facilities and equipment management.

6. Conclusion

In conclusion, the construction and implementation of the comprehensive management and control system for facilities and equipment in property services have achieved remarkable results. By effectively managing and controlling facilities and equipment, the lifespan of equipment has been significantly extended. This not only reduces the cost of frequent equipment replacement but also ensures the stable operation of property facilities, providing a more reliable living and working environment for users. Moreover, the system has greatly improved service quality. Through real-time monitoring and efficient maintenance scheduling, property management teams can respond promptly to equipment failures, minimizing the impact on users. However, there is still room for improvement. Future research could focus on enabling AI-powered autonomous maintenance. With the development of artificial intelligence technology, autonomous diagnosis and maintenance of equipment can be realized, which will further enhance the efficiency and accuracy of equipment management. In addition, exploring cross-platform integration strategies is also crucial. Integrating the management and control system with other property-related platforms, such as security systems and energy management platforms, can achieve more comprehensive and intelligent property management. These future research directions will help to continuously optimize the comprehensive management and control system, making property services more intelligent, efficient, and user-friendly.

Disclosure statement

The author declares no conflict of interest.

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