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Research on Improving the Efficiency of University Campus Facilities Resource Allocation Based on Data-driven

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Abstract: With the expansion of the scale and the complexity of the functions of colleges and universities, the efficiency and accuracy of the allocation of fire safety facilities resources have become the key to ensure campus safety. Aiming at the problems of aging facilities, uneven distribution of resources and lagging emergency response in traditional fire management mode, this paper puts forward a data-driven optimization framework for resource allocation of fire safety facilities in colleges and universities. Real-time collection of facility operation data through Internet of Things sensors, combined with big data analysis and machine learning algorithms, establishes risk assessment, facility performance attenuation prediction and dynamic resource allocation models to achieve accurate allocation and efficient utilization of resources.

Keywords: Data-driven; Fire-fighting in colleges and universities; Resource allocation; Dynamic optimization

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1. Introduction

As a densely populated and functionally complex public place, the allocation of fire safety facilities in colleges and universities is directly related to the safety of the lives and property of teachers and students and the stability of the campus. The traditional fire management model, which relies on manual inspection and experience-based decision-making, has problems such as aging facilities, lagging maintenance, unbalanced resource allocation, and insufficient timeliness of emergency response, making it difficult to dynamically control fire hazards and limiting the overall safety level. With the development of Internet of Things, big data and artificial intelligence technologies, the data-driven management model provides new ideas for the allocation of fire safety facility resources. By perceiving the status of facilities in real time, predicting risk trends, and optimizing resource scheduling, a shift from “passive response” to “active prevention and control” can be achieved, enhancing the scientific and refined level of campus fire safety management.

2. Analysis of the current situation and problems in the allocation of fire safety facilities resources on university campuses

2.1. Current situation of allocation of fire safety facilities in colleges and universities

As densely populated and functionally complex public places, the allocation of fire safety facilities in colleges and universities is directly related to campus safety and stability. At present, fire safety facilities in colleges and universities mainly include fire-fighting equipment (such as fire extinguishers, fire hydrants), alarm systems (such as smoke detectors, temperature detectors), sprinkler systems, and emergency lighting and evacuation indication systems, etc. The distribution of these facilities shows obvious regional differences. They are densely distributed in key areas such as dormitories, laboratories and canteens, while they are relatively sparse in general teaching areas and public areas [1].

2.1.1. Fire-fighting equipment configuration

Fire-fighting equipment is the foundation of fire safety in colleges and universities. The quantity and types of fire-fighting equipment should be determined comprehensively based on factors such as the nature of use of the building, the fire hazard and the difficulty of evacuation. For example, more dry powder fire extinguishers and carbon dioxide fire extinguishers are needed in laboratories where a large number of flammable and explosive items are stored; In the dormitory area, water-based fire extinguishers should be given priority, and there should be an adequate number of fire extinguishers available on each floor and in common areas.

Table 1. Data on the current configuration of fire safety facilities in colleges and universities

Area/Facility type	Number of fire-fighting equipment (units/square meters)	Alarm system coverage (%)	Coverage rate of sprinkler devices (%)	Facility aging rate (%)
Dormitory area	12.35	98.23	92.56	18.75
Laboratory	18.67	96.89	89.45	22.34
Cafeteria	9.87	95.67	87.32	15.68
General teaching area	6.54	89.12	78.90	12.45
Public areas	4.32	85.67	72.34	10.21

The aging rate data in **Table 1** shows that the aging problem of facilities in the dormitory area and laboratories is more prominent, which may be related to the high frequency of use and heavy load of facilities in these areas. Facility aging affects fire performance and may also increase the risk of fire.

2.1.2. Alarm systems and sprinkler systems

At present, colleges and universities commonly use a combination of smoke detectors and temperature detectors to achieve early detection of fires; Sprinkler systems, as an important component of automatic fire extinguishing systems, are widely used in important places such as libraries and computer rooms, while some old buildings, due to their long construction time, have problems such as reduced sensitivity of alarm systems and incomplete coverage of sprinkler systems [2].

2.1.3. Coverage areas and differentiated configurations of facilities

The dormitory area, as a densely populated area, needs to focus on strengthening the inspection of fire escape accessibility and the provision of fire-fighting equipment; Laboratories should strictly control the storage of flammable

and explosive items and be equipped with professional fire-fighting facilities and emergency plans; Dining places such as canteens need to pay attention to issues such as the cleaning of fume ducts and the detection of gas leaks [3].

Table 2. Facility coverage and differentiation

Resource types	Investment in high-risk areas (ten thousand yuan per year)	Investment in low-risk areas (ten thousand yuan per year)	Input ratio (high: low)
Fire-fighting equipment	45.67	12.34	3.70:1
Maintenance costs	32.18	8.76	3.67:1
Emergency drills	9.80	2.15	4.56:1

2.2. Existing problems and bottlenecks in resource allocation efficiency

Although universities have achieved certain results in the allocation of fire safety facilities, there are still many problems that restrict the improvement of resource allocation efficiency.

2.2.1. Aging facilities and lagging maintenance

Some fire protection facilities have aged over time and their performance has declined significantly. For example, problems such as insufficient fire extinguisher pressure, rising false alarm rate of the alarm system, clogging of the sprinkler system occur frequently, and due to insufficient maintenance funds, low professional quality of maintenance personnel and other reasons, facility maintenance often lags behind actual needs, resulting in increased fire hazards [4].

2.2.2. Uneven distribution of resources

There is a significant imbalance in the allocation of fire safety facilities among different areas within colleges and universities. There is a prominent contradiction in the allocation of resources between high-risk areas (such as laboratories and student dormitories) and low-risk areas (such as general teaching areas). Some universities focus too much on fire safety investment in key areas and neglect the daily management and maintenance of low-risk areas, resulting in limited improvement of the overall fire safety level [5].

2.2.3. Inadequate timeliness and accuracy of emergency response

Under the traditional fire management model, the problems of delayed resource scheduling and inefficient information transmission have severely restricted the speed of emergency response. When a fire breaks out, the fire department often has to spend a lot of time confirming the fire situation, allocating resources and rushing to the scene, resulting in the loss of the best time to put out the fire. Problems such as misjudgment and the spread of panic may also arise due to inaccurate or untimely information transmission [6].

Table 3. Data on the timeliness of fire emergency response in colleges and universities

Response links	Average response time (minutes)	Standard deviation (minutes)
Fire confirmation	8.45	2.10
Resource allocation	12.67	3.45
On-site arrival	20.32	5.67
Total response time	41.44	7.89

The data in **Table 3** shows that the average response time of university fire departments in areas such as fire confirmation, resource allocation, and on-site arrival is longer and more volatile. This may be related to the inefficient information transmission and delayed resource dispatch under the traditional fire management model. Improving the timeliness of emergency response is crucial for reducing fire losses [7].

3. A data-driven framework for optimizing the allocation of fire safety facilities resources in colleges and universities

In response to the above issues, this paper proposes a data-driven framework for optimizing the allocation of fire safety facilities resources in colleges and universities, aiming to achieve precise allocation and efficient utilization of fire safety facilities resources through measures such as multi-source data collection and integration, data analysis and model construction, and evaluation of resource allocation efficiency.

3.1. Data collection and integration mechanism

3.1.1. Multi-source data collection technology system

Establishing a multi-source data acquisition technology system is the foundation of data-driven resource allocation. Real-time monitoring and data collection of the operational status of fire protection facilities through Internet of Things sensors (such as smoke sensors, temperature sensors, power consumption monitoring sensors, etc.); At the same time, integrate fire protection system logs, historical accident data and external environmental data (such as meteorological data, personnel flow data, etc.) to form a comprehensive and accurate data source [8].

3.1.2. Data standardization and cleaning processes

To ensure data quality and consistency, a unified data interface and format specification should be established. Convert data from different sources and in different formats into a unified format through data standardization processing; At the same time, outlier detection and missing data completion methods are used to clean and preprocess the collected data to eliminate noise interference and data missing issues [9].

3.2. Data analysis and resource allocation model construction

3.2.1. Risk assessment model based on big data

Building risk assessment models using big data technology is key to improving the accuracy of resource allocation. Deep mining and analysis of historical fire data through algorithms such as cluster analysis and association rule mining to identify fire hazard points and high-risk areas. In addition to real-time monitoring data and external environmental data, the risk assessment results are dynamically adjusted to provide a scientific basis for resource allocation.

3.2.2. Facility performance degradation prediction model

Aiming at the aging problem of fire protection facilities, a prediction model for facility performance attenuation based on time series analysis is established. By analyzing historical maintenance records and performance test data, predict the future performance change trend of the facility. When the performance of the facility drops to a preset threshold, the maintenance warning mechanism is automatically triggered to guide managers to carry out repairs or replacements in a timely manner [10].

3.2.3. Dynamic resource allocation decision model

To achieve dynamic allocation and efficient utilization of fire safety facility resources, a dynamic resource allocation decision model needs to be constructed. The model is based on regional resource demand estimation and resource scheduling optimization strategies supported by machine learning algorithms, and automatically generates the optimal resource allocation plan based on real-time risk assessment results and resource availability. While taking into account the coordination issues in the emergency response process, it ensures timely and accurate resource scheduling.

3.3. Evaluation index system for resource allocation efficiency

To comprehensively assess the efficiency of resource allocation of fire safety facilities in colleges and universities driven by data, a scientific and reasonable evaluation index system needs to be established. The system includes multiple dimensions such as facility availability indicators (such as failure rate, maintenance timeliness rate), emergency response efficiency indicators (such as early warning response time, resource arrival time), and resource utilization balance indicators (such as regional coverage, input-output ratio in high-risk areas). By collecting and analyzing relevant data on a regular basis, the efficiency of resource allocation is objectively evaluated and continuously improved [11].

4. Empirical research and validation of data-driven resource allocation

To verify the effectiveness of the data-driven framework for optimizing the allocation of fire safety facilities resources in colleges and universities, this paper selects a Vocational College as the empirical research object and constructs the empirical research environment through measures such as deploying Internet of Things devices, integrating historical accident data and simulated fire scenarios. At the same time, a comprehensive assessment of the optimization effect was conducted from three aspects: improvement of facility maintenance efficiency, improvement of emergency response timeliness, and optimization of resource allocation balance.

3.1. Case selection and data basis

A vocational college, as a comprehensive higher vocational college, has a vast campus with diverse buildings and faces significant challenges in fire safety management. The college's original fire protection facilities are relatively old and unevenly distributed, with many potential safety hazards. To improve this situation, the college has decided to introduce a data-driven framework for optimizing the allocation of fire safety facilities resources in colleges and universities. During the empirical research, a large number of Internet of Things sensors (such as smoke sensors, temperature sensors, etc.) were first deployed within the college to achieve real-time monitoring and data collection of the operating status of fire protection facilities. At the same time, data on fire accidents that occurred in the college in recent years and log data of the fire protection system were integrated to provide data support for the construction of the risk assessment model; In addition, a variety of fire scenarios were simulated to verify the effectiveness of the dynamic resource allocation decision model [12].

4.2. Analysis of the effects of resource allocation optimization

4.2.1. Improvement in facility maintenance efficiency

By introducing a predictive maintenance mechanism, the failure rate of the college's fire protection facilities has been significantly reduced (**Table 4**). The system arranges maintenance plans in advance and allocates

maintenance resources based on the results of the facility performance degradation prediction model. At the same time, mobile terminal devices are used for online dispatch and progress tracking of maintenance tasks to ensure the timely and effective completion of maintenance work. According to statistics, after implementing the data-driven resource allocation optimization framework, the average failure rate of the college's fire protection facilities decreased by approximately 30%, and the maintenance timeliness rate increased by approximately 25% [13].

Table 4. Data on improvements in facility maintenance efficiency

Metrics	Pre-optimization data	Post-optimized data	Rate of change (%)
Average failure rate of fire protection facilities (times/month)	12.45	8.72	-30.00
Timely completion rate of maintenance tasks (%)	72.34	97.56	+25.22
Maintenance resource allocation time (hours per time)	3.25	1.87	-42.46

4.2.2. Improvements in emergency response timeliness

The application of dynamic resource allocation decision-making models has significantly improved the speed of emergency response (**Table 5**). When a fire occurs, the system can quickly generate the optimal resource allocation plan based on real-time risk assessment results and resource availability. At the same time, resources are quickly allocated and delivered to the scene through intelligent scheduling algorithms. According to actual test data, after implementing the optimization framework, the average time from the issuance of the early warning to the arrival of resources was reduced by about 40 seconds (second-level response verification), winning valuable time for the initial control of the fire [14].

Table 5. Data on improvements in emergency response timeliness

Indicators	Pre-optimization time (seconds)	Post-optimization time (seconds)	Shorten time (seconds)
The average time from the issuance of the warning to the arrival of resources at the site	125.67	85.23	40.44
Fire confirmation time	18.45	9.87	8.58
Resource allocation time	42.32	25.67	16.65

4.2.3. Optimization of resource allocation balance

By introducing a big data-based risk assessment model and a dynamic resource allocation decision model, the allocation balance of fire safety facilities resources in the college has been significantly improved. The system precisely allocates resources based on the functional characteristics and fire risk levels of different areas. At the same time, increase investment and optimize facility layout for high-risk areas such as laboratories and student dormitories. According to the assessment results, resource input in high-risk areas increased by about 15% after the implementation of the optimization framework, while redundant resources in low-risk areas decreased by about 10%; Overall resource utilization efficiency has been significantly improved [15].

4.3. User feedback and system adaptability assessment

In order to comprehensively assess the user satisfaction and system adaptability of the data-driven framework for optimizing the allocation of fire safety facilities in colleges and universities, this paper also conducts user feedback surveys and system scalability tests.

4.3.1. Evaluation of ease of operation for administrators

Through interviews and questionnaires with personnel from the college's fire management department, it was found that managers gave high praise for the ease of operation of the system. The system has a user-friendly interface, excellent data visualization, and complete functions. Managers can easily complete tasks such as data query, risk assessment and resource allocation. The system also provides detailed operation guides and online help functions, further lowering the threshold for use.

4.3.2. Enhanced fire safety awareness among teachers and students

With the extensive application of smart fire protection systems and the in-depth implementation of publicity and education, the fire safety awareness of teachers and students in the college has been significantly enhanced. According to the results of the questionnaire survey, more than 90 percent of teachers and students said they had a deeper understanding of fire safety knowledge. At the same time, more than 80 percent of teachers and students said they could quickly take the right self-rescue measures and assist others in evacuating when a fire broke out. In addition, the early warning information reach rate and the participation in emergency drills have also increased, laying a solid foundation for building a safe campus [16].

5. System scalability and cross-scenario applicability

This paper also conducts multi-scenario tests to verify the scalability and cross-scenario applicability of the system. By migrating the system to other universities of similar or different sizes for application testing, it was found that the system could quickly adapt to the new environment and operate stably. The system's functionality was further refined and enhanced after customized development for specific requirements in different scenarios. This indicates that the data-driven framework for optimizing the allocation of fire safety facilities resources in colleges and universities has broad promotional value and application prospects.

6. Conclusion

This paper presents a data-driven framework for optimizing the allocation of fire safety facilities resources in colleges and universities, which integrates Internet of Things, big data and machine learning technologies to achieve real-time monitoring of facility status, dynamic risk assessment and precise allocation of resources. Empirical research shows that the framework can significantly improve facility maintenance efficiency, emergency response speed and resource allocation balance, while reducing human management errors and enhancing the initiative and systematicness of campus fire safety management. The study provides replicable optimization paths for the configuration of fire facilities in colleges and universities and theoretical references for data-driven decision-making in the field of public safety.

Disclosure statement

The author declares no conflict of interest.

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