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Research on Innovative Smart Management Models for University Laboratories

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Abstract: Against the backdrop of accelerated construction of "Double First-Class" universities and "smart campuses," university laboratories, as core infrastructure platforms supporting talent cultivation and scientific research, are undergoing a transformation from traditional extensive management to digital, networked, and intelligent management. However, in practice, prominent problems such as fragmented information systems, lack of unified data standards, weak business collaboration, and insufficient intelligent applications still exist, constraining the overall effectiveness of laboratory resources. Based on a review of the current status of information-based laboratory management in universities, this paper analyzes the existing dilemmas from the perspective of top-level design and governance concepts, and proposes a smart management model centered on a unified platform, data middle platform, process reengineering, and intelligent empowerment. It then builds an application framework around key scenarios such as equipment life-cycle management, resource opening and sharing, and safety risk control, and finally puts forward implementation paths and safeguard mechanisms. The study argues that universities should incorporate smart laboratory management into their overall informatization strategy and promote it through the coordinated advancement of technical system reconstruction and institutional innovation, so as to truly realize the modernization and high-performance governance of laboratory management.

Keywords: University Laboratories; Smart Management; Informatization; Data Middle Platform; Management Model Innovation

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1.Current Foundation and Prominent Problems of Information-Based Management in University Laboratories

University laboratories play an increasingly important role in teaching, scientific research, and social services. The proportion of practical teaching hours continues to increase, the quantity and value of large-scale precision instruments keep growing, and the red-line constraints of laboratory safety are becoming more stringent. All these factors impose higher requirements on laboratory management. After years of development, most universities have established a certain level of informatization foundation in their laboratories, but there remains a substantial gap compared with the goals of building a "smart campus."

First, in terms of overall foundation, laboratory informatization in many universities still presents a "fragmented" pattern. At different stages and under the leadership of different departments, various business systems have been developed, such as asset management systems, large-scale instrument sharing systems, reservation systems, consumables and hazardous chemicals management systems, and environmental monitoring systems [1]. Most of these systems have been built independently around specific business objectives, lacking unified planning and architectural design, and using heterogeneous technical paths and data standards. As a result, it is difficult to realize interconnection and interoperability among systems. The same or similar data must be repeatedly entered and maintained in different systems, which not only wastes resources, but also undermines data consistency and accuracy.

Second, from the perspective of business operations, there are still obvious “online–offline disconnections” in key laboratory management processes. Links such as equipment project initiation and procurement, budget approval, and scrapping are often closely related to systems for state-owned assets, finance, and research management. Due to the lack of effective integration among these systems, staff frequently have to switch back and forth between paper forms, Excel files, and different systems. Approval procedures are cumbersome, and processing cycles are long. The linkage between experimental course scheduling, experiment project management, and laboratory opening management is also inadequate. Much data is still recorded offline, making it difficult to form a complete process data chain [2].

Third, in terms of data resources, laboratory-related data is characterized by “multi-source heterogeneity, lack of standards, and weak governance.” Equipment ledgers, experimental projects, course data, research projects, personnel information, safety records, and energy consumption data are scattered across multiple systems and departments, with non-unified data calibers and inconsistent field definitions being widespread. For example, the name, category, and ID of the same instrument may differ between the state-owned assets system and the laboratory management system; experimental courses and experimental projects lack unified coding and association mechanisms, affecting teaching data analysis and quality evaluation. The absence of a unified data standards system and data governance mechanism hampers data integration and deep application [3].

In addition, in terms of intelligence level, most current applications still remain at the basic stage of “querying and statistics.” Some universities have adopted technologies such as access control systems, video surveillance, and environmental sensors to realize real-time monitoring of personnel entering and leaving laboratories and the environmental status, but the data is often used in isolation and not deeply integrated with business processes and decision analysis. Applications based on big data and artificial intelligence, such as equipment fault prediction, resource optimization scheduling, and safety risk assessment, are still in the exploratory or blank stage, and the “efficiency-enhancing” role of intelligent technologies in management has not been fully brought into play [5].

Finally, in terms of management teams and governance mechanisms, laboratory management staff generally possess rich business experience, but have relatively weak informatization awareness and data thinking, and low participation in system construction and data application. At the university level, there is usually no dedicated team focusing on laboratory informatization and data governance. The construction of information systems relies heavily on external vendors, while internal capabilities and mechanisms for continuous iterative optimization are insufficient. At the institutional level, there is also a lack of processes, evaluation systems, and incentive and constraint mechanisms compatible with smart management, leading to the common phenomenon that “systems are built but not well used” [4].

It is thus evident that the problems facing information-based management of university laboratories are systemic and structural, involving both technical architecture and governance concepts and mechanisms. To achieve genuine “smartness,” an overall reconstruction at the management model level is required, rather than limited upgrades to local systems or simple function stacking.

2.Goal Positioning and Overall Architecture of Smart Management Models for University Laboratories

Under the requirements of high-quality development of higher education in the new era, the goal of smart laboratory management is not only to improve work efficiency, but more importantly, to build a key foundational platform that supports the modernization of university governance. In light of real-world problems and technological development trends, the objectives of smart management models for university laboratories can be summarized as: taking data as the core resource, taking platforms as the supporting carriers, taking processes as the main management thread, and taking security as the baseline constraint, so as to realize integrated allocation of laboratory resources, full-process visibility, controllable risks, and scientific decision-making.

Around this goal, the overall architecture of the smart laboratory management model can be summarized as “one overarching principle, two supports, and three priorities.” The “one overarching principle” means that under the university’s overall informatization and “smart campus” top-level design, smart laboratory management should be incorporated into the unified planning of the university’s governance system and informatization development. The relationships and interfaces between laboratory management and systems for academic affairs, research, state-owned assets, finance, and human resources should be clarified, so that laboratory management becomes an important component of the university’s digital governance.

The “two supports” refer to a unified business service platform and a laboratory data middle platform. The unified business service platform targets different roles such as students and faculty, laboratory administrators, and functional department managers, providing a unified entry point and differentiated services, thus realizing unified identity authentication, unified business acceptance, and unified information display. By integrating originally scattered business systems through this platform, relevant functions can be classified, optimized, and reconstructed to form business subsystems for equipment management, experimental teaching management, safety management, and open sharing management. The laboratory data middle platform, facing all business systems and IoT devices, is responsible for data collection, cleansing, integration, modeling, and service provision. By formulating unified data standards and coding rules, it builds core data resource repositories such as equipment master data, personnel master data, and experimental project master data, and provides high-quality data services for upper-layer business applications and decision analysis.

The “three priorities” are reflected in three categories of smart management applications built atop the platform and middle platform: first, refined full life-cycle management of equipment and resources, covering the entire process from equipment initiation, procurement, acceptance, capitalization, use, maintenance, to scrapping, so that asset status becomes visible, responsibilities traceable, and benefits assessable; second, process-based data management and analysis of experimental teaching and research activities, by associating experimental courses, experimental projects, student learning behaviors, and research project data, to support improvement of teaching quality and evaluation of research performance; third, intelligent monitoring of laboratory safety and environment and risk early warning, by interfacing with access control, video surveillance, environmental sensors, and hazardous chemicals management systems, to realize comprehensive perception and risk control regarding “people, machines, materials, environment, and management” [3].

Under this overall architecture, information technology is no longer merely a “supporting tool,” but is deeply embedded into laboratory management processes and governance mechanisms. The layered design of platform and middle platform allows business applications to evolve flexibly and data resources to be governed in a unified manner, thus meeting current management needs while reserving room for the introduction of future technologies and new businesses. In terms of management patterns, this means a shift from past “passive recording” and “ex-post statistics” to “proactive perception,” “real-time analysis,” and “intelligent decision-making.”

3.Key Application Scenarios and Implementation Logic under the Smart Management Model

On the basis of clarified goals and architecture, the value of the smart management model must ultimately be realized in concrete application scenarios. Focusing on the core business of university laboratory management, the implementation logic of smart management can be sorted out from several aspects, including equipment life-cycle management, open sharing of experimental resources, laboratory safety management, and performance evaluation.

In terms of equipment life-cycle management, the core of smart management is “full-process online operation, data connectivity, and visible status.” The unified business platform incorporates all links related to equipment into process management, from project justification, budget application and approval, procurement implementation, acceptance, and capitalization, to installation and commissioning, usage registration, maintenance, metrological calibration, fault repair, technical transformation, and scrapping. The data middle platform establishes a complete “digital file” for each piece of equipment, recording information such as purchase time, technical parameters, usage frequency, energy consumption, number of failures, and maintenance costs [2]. Managers can use visual interfaces to grasp the real-time status and historical trajectory of equipment and, by analyzing the relationship between equipment utilization and the research outputs and teaching courses it supports, provide evidence for equipment sharing, configuration optimization, and renewal decisions. Based on accumulated historical fault and operation data, predictive models can also be trained to realize health assessment and maintenance strategy optimization for key equipment, gradually shifting from “post-event repair” to “preventive maintenance.”

In terms of open sharing of experimental resources, smart management focuses on “a unified entry point, clear rules, and optimized allocation.” Laboratory resources include specialized laboratories, large-scale instruments, and various public platforms, which were often managed separately by different schools or units in the past, with information stored in local systems or on paper records, making it difficult for other students and faculty to accurately access resource information. Through the unified business platform, all laboratory resources that can be opened across the university can be centrally displayed, forming a “single list of resources” available to the entire campus. Teachers and students can query information such as equipment performance, available time slots, and reservation rules according to their access rights, and submit reservation requests online. The system, taking into account experimental course schedules, equipment maintenance plans, laboratory capacity, and safety constraints, automatically determines whether the reservation can be made and provides reasonable arrangements. For high-value instruments, mechanisms such as fund settlement, usage records, and linkage with research outputs can be embedded in the system, facilitating cross-school sharing while supporting subsequent performance statistics and cost accounting.

In terms of laboratory safety management, the key to smart management lies in “all-factor perception, prioritized risk control, and closed-loop management.” By accessing the access control and identity authentication systems, controllable and traceable entry and exit of laboratory personnel can be achieved, and safety training and examination results can be bound to access permissions to ensure that personnel who have not passed relevant training are not allowed to enter the corresponding laboratories or operate high-risk equipment [3]. By deploying environmental sensors, real-time monitoring of key parameters such as temperature, humidity, concentrations of toxic and harmful gases, and electrical loads can be carried out. Once safety thresholds are exceeded, the system automatically sends out alerts and can link ventilation, power-off, and access control facilities to implement interventions. The hazardous chemicals management system records the entire process of procurement, warehousing, distribution, return, and disposal of each hazardous chemical, preventing excessive storage and improper use. By aggregating data from access control, environmental monitoring, hazardous chemicals management, and video surveillance through the data middle platform, safety risk evaluation models can be built to carry out graded assessment and trend analysis of safety risks in different laboratories, shifting the focus of safety management from “incident handling” to “risk identification and prevention”.

In terms of performance evaluation and decision support, smart management emphasizes “data-driven evaluation and usage-driven construction.” Through the data middle platform, laboratory resource inputs (such as equipment purchases and operation and maintenance expenditures) can be linked with outputs (such as the number of courses supported, number of students covered, research projects, publications, patents, and technology transfer achievements), so as to objectively reflect the overall effectiveness of different laboratories and different instruments [4]. On this basis, universities can optimize the structure of resource allocation, increase investment in high-efficiency platforms, and integrate or adjust resources that have long operated inefficiently. For experimental teaching, the teaching value of experimental projects can be evaluated and experimental teaching reform can be guided by analyzing student experimental data, course attainment, and resource consumption in experimental teaching sessions. In addition, the system can provide data support for medium- and long-term laboratory construction planning in universities, such as identifying weaknesses in experimental conditions in different disciplines and key directions for platform construction.

Through the systematic linkage of the above scenarios, the smart management model can form a closed loop across the multiple dimensions of “people–machines–materials–environment–management,” achieving comprehensive visualization of laboratory operation status and scientific management decision-making. Importantly, these applications do not exist in isolation, but are collaboratively implemented based on the unified platform and data middle platform, avoiding the traditional fragmented construction pattern of "one system for each new requirement."

4.Implementation Path and Safeguard Mechanisms for Smart Laboratory Management Models

The construction of smart management models is a comprehensive transformation process involving technology, management, and culture, and requires a rational implementation path and supporting safeguards.

In terms of implementation path, universities should first accomplish top-level design and status assessment. By investigating and sorting out laboratory resources and management processes across the university, clarifying the existing information systems and the status of data resources, identifying key problems and priority transformation areas, universities can define the objectives, phased tasks, and construction roadmap for smart laboratory management within the framework of their overall informatization strategy [1]. On this basis, unified data standards and interface specifications should be formulated to pave the way for subsequent system integration and data aggregation.

Subsequently, a strategy of "focusing on key breakthroughs, piloting first, and gradual rollout" can be adopted. Universities can select colleges or laboratory platforms with relatively sound management foundations, strong willingness for informatization, and representative business types as pilot units. Around key businesses such as equipment management, safety management, and open sharing, comprehensive pilots can be carried out, with the core functions of the unified business platform and data middle platform being deployed on a small scale to verify the adaptability and feasibility of the architectural and functional designs. By analyzing pilot operation data and user feedback, process settings and system functions can be adjusted in a timely manner. After a relatively mature solution has been formed, it can be gradually promoted across the university in stages.

In terms of safeguard mechanisms, the first priority is to strengthen team building and organizational coordination. Universities should establish a cross-departmental working mechanism for laboratory informatization, bringing laboratory management, informatization construction, network security, state-owned assets management, academic affairs, and research management into a collaborative framework, and forming regular channels for communication and coordination [4]. On this basis, through training, project practice, and talent introduction, universities can cultivate composite teams that are familiar with laboratory operations as well as information technology and data analysis, enabling them to play key roles in the planning, implementation, and operation of smart management models.

Second, a solid foundation of network and data security must be established. In accordance with national laws and regulations on cybersecurity and data security, security level protection assessments should be carried out for laboratory management systems, and mechanisms for identity authentication, access control, log auditing, intrusion prevention, and backup and disaster recovery should be improved. Sensitive information such as equipment ledgers, personal data, research data, and hazardous chemical data should be subject to graded and categorized management and the principle of least-privilege access, and necessary data masking and encryption technologies should be adopted to ensure data security throughout the entire process of collection, transmission, storage, and use [3].

Third, dual guarantees at the institutional and cultural levels should be established. Universities should incorporate system usage and data quality into laboratory management assessment indicators, and reasonably link data entry, system operation, and process execution with individual and departmental performance to avoid "emphasizing construction while neglecting use." Through continuous publicity and training, the significance and value of smart management should be explained to students and faculty to enhance their willingness to use and participate, and gradually foster a management culture of "relying on platforms to handle business and using data to support decision-making" [4].

Overall, innovation in smart management models for university laboratories is a concrete manifestation of the deep integration of information technology and the higher education governance system. By establishing the foundation through a unified platform and data middle platform, leading with key application scenarios as exemplars, and supporting with institution-building and team development, laboratory management can move beyond the predicament of "multiple, separate constructions, fragmented data, and cumbersome processes" toward a new stage of systematic, scientific, and high-performance governance. This will not only help to improve the quality of experimental teaching and the capacity to support scientific research, but will also contribute significantly to the modernization of overall university governance capacity.

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