Design of University Laboratory Management System based on Problem and Goal Orientation

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Abstract: With the increasing scale of laboratories and experimental teaching activities in colleges and universities, laboratory management affects teaching quality, scientific research and school-running directly. The construction of laboratory management system has also become an important part to improve the laboratory management. Based on key problems faced during laboratory management and expected construction goals, this paper establishes an abstract laboratory management system model, analyzes its structure, data, transactions, and key points, and gives a practical design scheme finally.

1. Introduction

University laboratory is the basic platform to carry out experimental teaching, cultivate students' practical ability and teachers' scientific research innovation, thus it is an important symbol to measure the comprehensive strength of a university [1,2]. Laboratory management directly affects teaching's quality, scientific research's level. With the increasing scale of laboratories and experimental teaching activities in colleges and universities, laboratory management system has become a typical means to improve the laboratory management level technically [3,4]. Laboratory management system's functions usually include but are not limited to: 1) Realize centralized and unified management of laboratory resources and data; 2) Provide intuitive and dynamic visual display of relevant laboratory resources and data, which is convenient for management, maintenance, and self-service; 3) Digitization of laboratory-related activities and resource life cycle; 4) Efficient statistical analysis and report on demand. Based on key problems faced by laboratory management and expected construction goals, this paper puts forward a practical design scheme of laboratory management system by analyzing an abstract model.

2. Key problems and construction goals of laboratory management

2.1 Key problems

Key problems faced by laboratory management in colleges and universities can be attributed to data and transactions. Data is the basis of management and the storage form of information in system. Transaction refers to the complete process of completing a management activity, including initiating a transaction, processing data, and feeding back results.

Key problems [5,6] commonly include: 1)Too many manual records, which are easy to make mistakes and lose, and inconvenient to use; 2) Incomplete data records without updating in time, while others are repeatedly counted; 3) Data storage is scattered and difficult to share, with many versions and lack of query entries; 4) Data does not guide the top-level planning effectively, which leads to repeated condition construction; 5) No active summary of data, so many reports are edited manually without correlation analysis; 6) Low-level and inefficiency management relying on subjective

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experience; 7) Lack of overall planning of resources, coexistence of idle aging and high-frequency use of equipment, life cycle of equipment and consumables are difficult to trace; 8) Multi-head management of resources and complicated management procedures; 9) Temporary tasks such as teaching, inspection and visit always need many times of communication and adjustment; 10) Teachers and students are unclear about laboratory resources, and laboratory utilization rate is low; 11) Advanced instruments and equipment, excellent management experience, experimental teaching methods and other resources are difficult to share; 12) Safety monitoring is mainly based on manual inspection, which is inefficient and flawed.

2.2 Construction goals

While solving the above problems, laboratory management expects to achieve following goals: 1) Flexible display of laboratory pedigree. Users can view resources from different perspectives such as disciplines, levels, majors, and courses; 2) Flexible decentralization of management authority. Management is mainly based on laboratories, teaching and research institutes, and can be delegated to experimenters. 3) Flexible resources' association. Relationship between laboratory and area, equipment and responsible departments is more flexible. 4) Combination with digital campus. Management system can reuse digital campus's data and facilities, such as personnel and course scheduling data. 5) Meet individual needs. Management system should not only meet the common management needs, but also keep customized interface to meet any special individual needs. 6) Meet colleges and universities' high-level planning.

3. Laboratory management system model

3.1 Model overview

Laboratory management system belongs to information resource management information system. By providing information management, processing, and circulation services, it helps personnel to implement management activities such as planning, execution and evaluation more scientifically, normatively, and efficiently. It can be considered as a digital twin system [7]. As shown in Figure 1, management system stores information of personnel, resources, rules, environment with data, and provides various transaction interfaces, and handles transactions according to preset logic, while results will serve as basis for real activities.

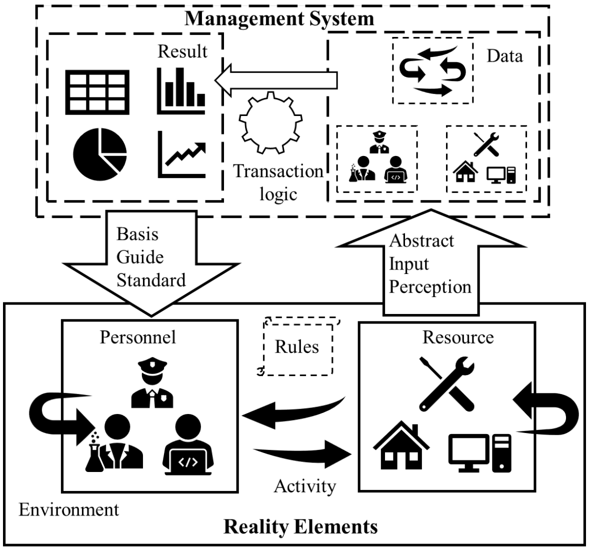

Figure 1 Relationship between Laboratory Management System and Reality Elements

As a digital twin system, laboratory management system needs to reflect the reality comprehensively, timely, and accurately.

(1) Comprehensive. All basic data that can be obtained from reality should be stored, and all practical activities involving basic data should be recorded as transactions. On the contrary, all daily

transactions involve operations of basic data, and all operations of ordinary users on basic data must be carried out through daily transactions. Whether a piece of information is regarded as basic data and whether an action is regarded as a transaction depends on management rules.

(2) Timely. Updating of objects in reality must be reflected in system's basic data, and be visible to all transactions. At the same time, system will advance corresponding transactions according to transaction logic to avoid inconsistencies between transactions or between transactions and reality. The standard of "timely" varies according to transaction requirements or supporting technologies.

(3) Accurate. Basic data should reflect reality accurately, and the transmission network should be reliable, and transaction logic conforms to management rules and realistic logic. For example, if an equipment's state changes to maintenance, then the inquiry number of available equipment should be reduced by 1.

3.2 Model structure

Research on any system's operation law should focus on its structure and function. Structurally, management system's model is roughly divided into four layers as shown in Figure 2.

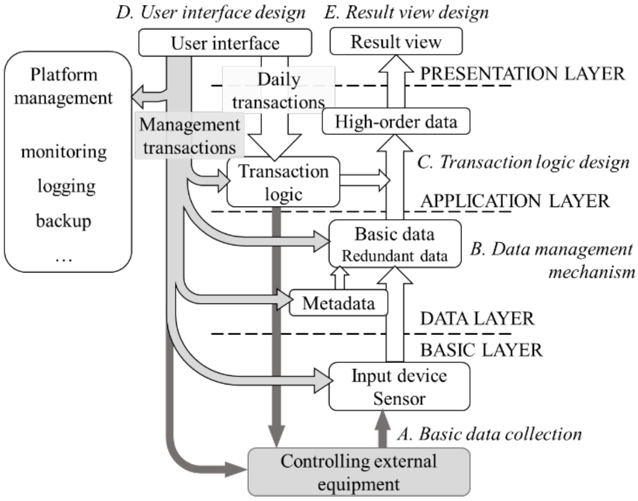

Figure 2 Management System Structure

Presentation layer is the layer directly accessed by ordinary users, mainly including user interface and result view; Application layer contains all logic of laboratory management transactions and transactions' results generated as high-order data; Data layer stores basic data, metadata, and redundant data, which supports Application layer's operation on data; Basic layer is hardware foundation of system operation, including network, storage, host, and data input devices.

3.3 Data in model

According to processing mode and function, data in the system can be divided into basic data, high-order data, metadata, and redundant data.

(1) Basic data. Basic data is an abstraction of real objects, such as personnel, resources, environment, and activity, etc., from management perspective, so it needs to be obtained from real world and updated when real objects changes. The specific collection and update mechanism varies with objects' type and automation degree. Fields contained in basic data depend on management rules. Transaction's basic data involves two aspects: real activity and system operation. For example, a borrowing transaction's real activity data includes lender, borrower, borrowing object and period, etc., while its system operation includes transaction's initiator and initiating time, etc.

(2) High-order data. High-order data is a query or statistical result generated by logical processing of basic data. Some simple high-order data can be used as calculation fields of basic data tables without complex transaction logic, such as calculating age by birth date.

(3) Metadata. Metadata is the data that describes data's organization, transaction meaning and relationship, such as generation method of calculation fields, collection of values of category data, scope of quantitative data, etc. Metadata is set by system developers and administrators according to

management rules and logic, and cannot be easily modified.

(4) Redundant data. Redundant data has nothing to do with management transactions, but can be accessed in the system, such as detailed introduction information of resources. Redundant data enriches description details, and its inconsistent with reality will only affects users' cognition, but does not affect management transactions.

Further information collection and modeling of resources belong to constructing information laboratory's scope, such as monitoring the progress of each experimental platform, building a virtual laboratory, etc. However, information laboratory can be a link resource of the management system.

3.4 Transactions in model

According to processing method, transactions are divided into daily transactions and management transactions.

(1) Daily transactions. Daily transactions are transactions that process basic data according to transaction logic, and usually produce high-order data and show them in preset views. Daily transactions are initiated by user interface in presentation layer, and data required are provided by data layer and input by users, such as query conditions. Actual process of a transaction varies with transaction's type and automation's degree. Transactions can be initiated from inside the system, such as a real-time big data view, and sending prompt information to an overdue borrower; It can also be initiated from outside, such as user inquiry or fire alarm.

(2) Management transactions. Management transaction does not operate data based on transaction logic, but set transaction logic, data, device parameters and so on directly. Management transaction also includes platform management transaction, which means information system's general transaction unrelated to the laboratory management field, such as system state monitoring, logging, backup, basic parameter setting and so on.

In addition, as an information resource management information system, laboratory management system is mainly responsible for information's management, processing, and circulation, but not involve the transformation of information energy into physical energy, chemical energy, and other energy modes. Therefore, controlling external equipment belongs to the extension functional, such as controlling fire extinguishing devices, or controlling robots to find and distribute resources, etc.

3.5 Key points

In view of above problems and goals, key points in construction of laboratory management system includes:

(1) Basic data collection. Basic data collection is the interface for system to perceive reality. In order to improve management efficiency, system should connect with reality actively, perceive any changes of personnel, resources, environment, and activities, and convert them into basic data for collecting.

(2) Data management mechanism. Data management mechanism provides reliable data services for system, ensures smooth data transmission and access links, and timely obtains and updates basic data, thus ensuring that all data accessed by transactions depicts a latest realistic state.

(3) Transaction logic design. Transaction logic design defines system's requirements and management rules as clear data operation logic. System not only runs general transaction logic, but also supports special needs of laboratories, resources, and personnel. Therefore, transaction logic design should be flexible, extensible, and customizable.

(4) User interface design. Good interface design can reduce users' learning time and improve interaction efficiency. In addition to traditional menu-based interface, complex functions can use graphical interfaces, such as designing interfaces in combination with laboratory pedigree diagrams.

(5) Result view Design. System should provide different results views according to requirements, and support further operations, such as comparative analysis between different results. Form can be reports, graphics, etc., timing can be periodic refresh display, or pop-up display automatically, such as experiment cancellation caused by meteorological conditions change.

Key points' position in system is shown in Figure 2, and its relationship with goals or problems is shown in Table 1:

Table 1 Relationship between key points and goals or problems

Problem or Goal	Basic data collection	Data management mechanism	Transaction logic design	User interface design	Result view design
Prob 1	√	√	√		
Prob 2	√	√			
Prob 3	√	√		√	√
Prob 4		√	√	√	√
Prob 5		√	√	√	
Prob 6	√	√	√		
Prob 7	√	√	√		√
Prob 8		√	√		
Prob 9	√	√		√	√
Prob 10			√	√	√
Prob 11			√	√	√
Prob 12	√		√		
Goal 1			√	√	√
Goal 2		√	√		
Goal 3		√	√		
Goal 4	√	√			
Goal 5			√	√	√
Goal 6			√	√	√

4. Design practice

Based on analysis of laboratory management system model, this section introduces the design practice of data, transactions, and key points.

4.1 Data design

According to associated objects, data is divided into personnel data, resource data, rule data, environment data and transaction data. Personnel data confirms personnel privilege and constitutes transaction records. Resource data is divided into areas, equipment, consumables, and other categories according to management and using methods. Rule data includes laboratory organization structure, management system, operation specification, etc., and is also reflected in transaction processing logic. Environmental data records have an impact on laboratory management, which refers to environmental factors that are difficult to be changed by human resources. Transaction data records reality activities and operation on management system. Personnel data and resource data constitute the main body of basic data:

(1) Personnel data. Each user has a unique ID and multiple roles. Roles distinguish between managers and non-managers, and their multiplicity lies in the fact that roles vary with time and scope. For example, an administrator of a laboratory may be a normal user of another laboratory or a temporary class administrator. Managers have corresponding authority to start management transactions and daily transactions, while non-management personnel only have corresponding daily transactions authority.

(2) Resource data. Resource data's attributes reflect their responsible unit and person, special nature (such as nuclear, chemical, and biological dangerous goods, security level) and so on. Resource data is related to asset data of financial system, but more highlights the experimental needs.

4.2 Transaction design

(1) Daily transactions. 1) Basic functions. Functions provided by all transactions, such as query, entry, import, export, report, etc. 2) Laboratory personnel management. Including setting role and management of experimental administrators' team; 3) Laboratory safety management. Including

management of daily safety, dangerous goods, secret-related special resources, safety education, etc. 4) Laboratory resource management. Including general task assignment and usage records, laboratory transactions, equipment installation transactions, consumables transactions, etc. 5) Open laboratory management. Including management of experimental subject, experimental process, temporary task, and related rules and regulations, basic operation training, etc. 6) Laboratory construction and evaluation management.

(2) Management transactions. 1) Transaction logic settings. Change transactions' judgment logic and set their default value uniformly. Laboratory administrators can modify some specific rules on their own as needed, such as changing resource allocation's priority; 2) Metadata management. Managing field composition and calculation method of various basic data. Personalized fields can also be added, such as security requirements. In addition, laboratory pedigree [8] is also described by metadata, which reflects laboratory resources' hierarchy and correlation, and matches the actual discipline pedigree and teaching curriculum design; 3) Platform management and other management, such as log management, backup management, data statistics, and setting related equipment.

4.3 Key point design

(1) Basic data collection. The most important is to carry out resources' information transformation, and connect laboratory resources with the system. The transformation methods involve: 1) upgrading the resources themselves or transformation methods, such as adding positioning sensing functions for resources, installing RFID electronic tags to record the status and position of equipment in real time; 2) Upgrading equipment management methods, such as changing registering from manually to scanning, or improving accuracy and real-time performance of data collection using the Internet of Things technology.

(2) Data management mechanism. Based on general platform management technology, it emphasizes deep integration with existing digital campus, including building a smooth information link based on digital campus's backbone link, establishing closer links between various management objects such as transformed information resources, and speeding up data and information's exchange within two system. All database should be consistent with the existing database, such as digital campus, financial assets, etc., especially the educational schedule data. Realize data's import and export mechanism with existing databases, and consider introducing RPA (robot process automation) [9] platform for cross-platform and system operation.

(3) Transaction logic design. Transaction logic is determined by realistic management rules, personnel experience, and common-sense logic. Transaction logic is obtained by top-down analysis of management requirements. For example, basic transactions and general basic data fields are determined by university institutions firstly, and then each department and office do supplements according to their own characteristics.

(4) Design of user interface and result view. Due to different areas, transactions and users, user interface and result view can be placed in computers, smart phones, sensors, multimedia devices and other hardware, and interaction styles may be voice, buttons, touch screen, face recognition and so on. Based on laboratory's pedigree diagram, system provides an intuitive navigation interface for resources and transactions, and dynamically displays a real-time data view that is convenient for visual command, scheduling and evaluation. Pedigree node can link related resources and expand redundant information, such as laboratory can link its rules and regulations, related news, introduction, learning resources, and virtual laboratory.

5. Conclusion

Laboratory management system establishes closer information communication among laboratory resources and forms a more efficient experimental resource system: 1) For resources, it improve use efficiency and intensive costs. Make effective use of idle resources, and promote resource sharing; 2) For students, it lay a foundation for open practice teaching and experimental service, which can cultivate students' subjective initiative and improve their practical ability; 3) For management, it improves management efficiency and service level of various transactions. Managers are more convenient to know laboratory pedigree, experimenters team, equipment's life cycle; 4) For colleges and universities, it enhances scientific of laboratory construction's planning and quantitative evaluation, strengthen supervision and management of laboratory construction, and effectively promote practical teaching, scientific research and personnel training.

The development of management system inevitably involves automation and intelligent upgrade, both upgrades do not change abstract system structure, but makes the system emerge automation and intelligent characteristics by improving its infrastructure and transaction logic model: automation means that system automatically completes user's preset process and gives users predictable information. Intelligent means that system automatically gives users unexpected information that may be needed, and realizes functions that users have not preset, thus acting like an agent with initiative. These are directions that can be further studied.

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