Research on Development and Application of Intelligent Cluster Management Platform for Shield Machine

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Abstract. Aiming at the problems of data acquisition, data storage, and equipment management that are caused by the scattered positions of shield machines during the simultaneous construction of multiple projects, an intelligent cluster management platform for shield machines is designed. Focusing on the key technologies of platform building and application from the aspects of overall platform architecture, data acquisition, data transmission, data storage, this paper proposes an intelligent cluster management platform, which integrates the functions of multi-project centralized monitoring, multi-terminal access and collaborative management. This paper provides guidance for the building of similar cluster management platform from the aspects of technology development, system application and comprehensive management, improving the construction efficiency and intelligent management level for shield machines.

1. Introduction

At present, with the rapid development of the construction machinery industry, tunnel boring machines (hereinafter referred to as "shield machine") have been widely used in underground space construction such as railways, highways, water conservancy and urban rail transit. The increasing number and the extensive distribution of shield machine bring great difficulties to the unified management, risk control, and timely equipment dispatching of shield machine construction [1]. Countries all over the world pay more and more attention to the research on combining the new information technology with shield machine condition monitoring, health diagnosis and management, so as to realize remote, intelligent, scientific and all-round equipment operation and maintenance. Therefore, it is important to carry out the research on development and application of intelligent cluster management platform to promote intelligent construction [2,3].

An integrated management platform based on industrial Internet architecture is built in combination with the new information technologies such as Internet of Things, cloud computing and big data [4,5,6]. Focusing on the key technologies of platform building and application from the aspects of overall platform architecture, data acquisition, data transmission, and data storage, this paper proposes an intelligent cluster management platform for shield machines which integrates centralized monitoring, multi-terminal access, and collaborative management, and provides guidance for the building of similar cluster management platform from the aspects of technology development, system

application and comprehensive management, and improves the intelligent management capability of shield machines.

2. Design of Overall Platform Architecture

The platform adopts B/S architecture mode, and is mainly divided into data acquisition layer, data transmission layer, data processing layer, data analysis layer, data storage layer, application service layer and data presentation layer, as shown in Figure 1.

1) Data acquisition layer: data acquisition is carried out through PLC and sensors during construction.

2) Data transmission layer: data transmission is carried out through Kafka layer.

3) Data processing layer: cleaning, dimensionality reduction and processing is performed.

4) Data analytics layer: using the Master-Worker mechanism, when Master receives a task, split the task.

5) Data storage layer: the collected data is stored through Redis, SQL Server and MongoDB.

6) Application service layer: the existing business logic and application services is processed.

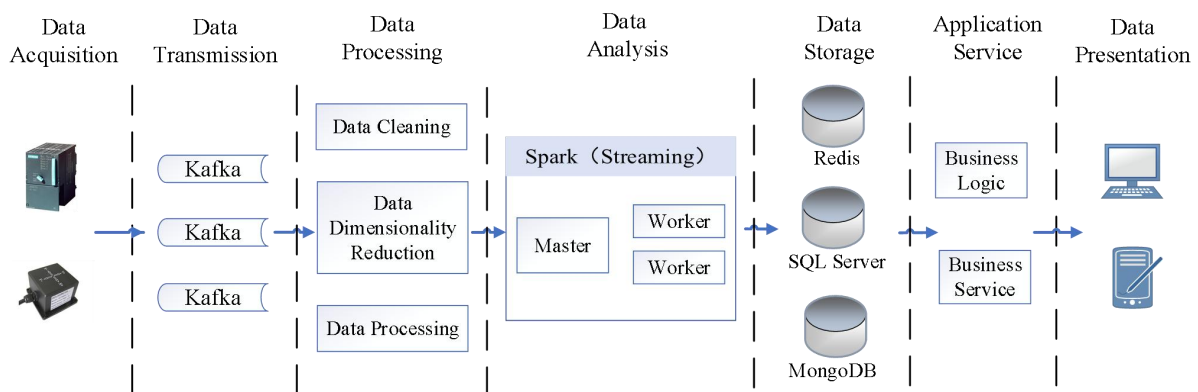7) Data presentation layer: interaction between pages and data.

Figure 1. Platform Architecture.

3. Data Acquisition and Storage

In the process of shield machine construction, the data swill be collected, transmitted, stored and visually monitored, and a professional database will be built to provide data support for the upper application.

3.1 Data Acquisition Content

Data acquisition of shield machine is the foundation for the cluster management platform. However, due to the complexity of shield machine, harsh construction environment, variety of data types and large amount of data concurrency, data acquisition is difficult [7]. Through sorting and classifying the collected contents, corresponding acquisition schemes are designed for different collected contents. The data collection contents are shown in Table 1.

Table 1. Data Acquisition Content.

Acquisition Type	Acquisition Item
Tunneling Parameter	Shield machine operation data, operation time, ring number, key parameter category, etc.
Equipment file data	Shield machine ID, equipment type, manufacturer, contractor,

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	project location, etc.
Geological data	Construction route, rock and soil type, environmental data, land subsidence data, etc.
Construction data	Construction quality, construction risk sources, engineering documents, personnel information, work division, etc.

3.2 Data Acquisition Design

Data extraction scheme with strong compatibility is the key technology for data acquisition of shield machines with different types and specifications. Most of shield machine construction projects will be equipped with a ground monitoring system to monitor the operation of equipment, and such system is connected with the PLC of shield machine through optical fiber [8].

Traditionally, data acquisition is mainly carried out through software acquisition or "black box". The former affects the stability of device running programs, while the latter is complex and expensive to deploy [9]. The data acquisition system is integrated into the ground monitoring software, which reduces the occupation of memory by software operation, thus realizing the display and local upload of monitoring data. The ground monitoring equipment adopts dual network segments, and the shield machine data does not communicate with the outside, thus ensuring the safety of shield construction data. Data is transmitted by Kafka and socket technology, and distributed to Redis cache and MongoDB database for storage. The data acquisition architecture is shown in Figure 2.
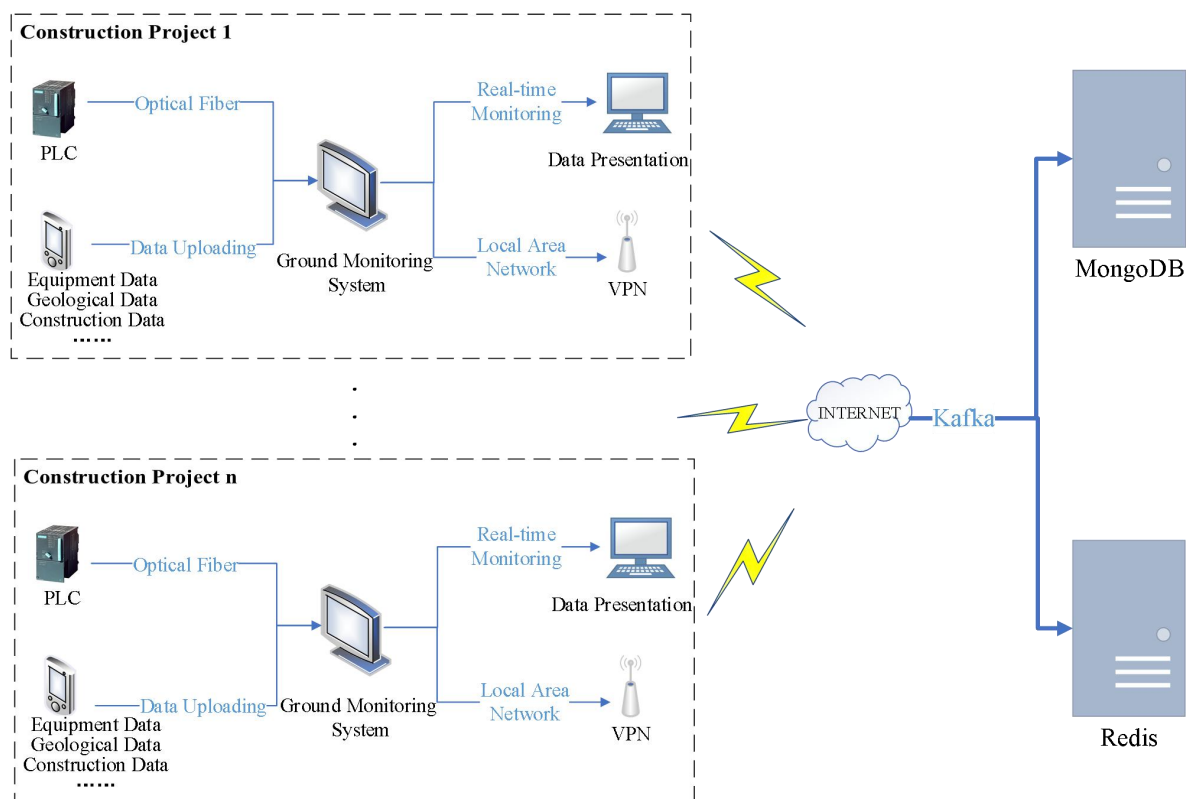

Figure 2. Data Acquisition Architecture.

3.3 Data Transmission Technology

Data transmission is to transmit data to the server through a specific protocol for storage and

processing. Kafka communication technology is adopted in the platform because of large amount of concurrent data and variety of data type, which avoids downtime when a large number of data requests are received at the same time to the server [10]. The data transmission process is shown in Figure 3.

1) Kafka places the requested data in the Kafka server queue through the producer, and places the data in sequence.

2) After receiving the data sent by the producer, the leader distributes the information to each processing unit, and the processing units transport the data according to their capacity until all data processing is completed.

3) Kafka will open up a disk space separately at the beginning. After all data processing is completed., the data will be written in sequence and stored in the disk.
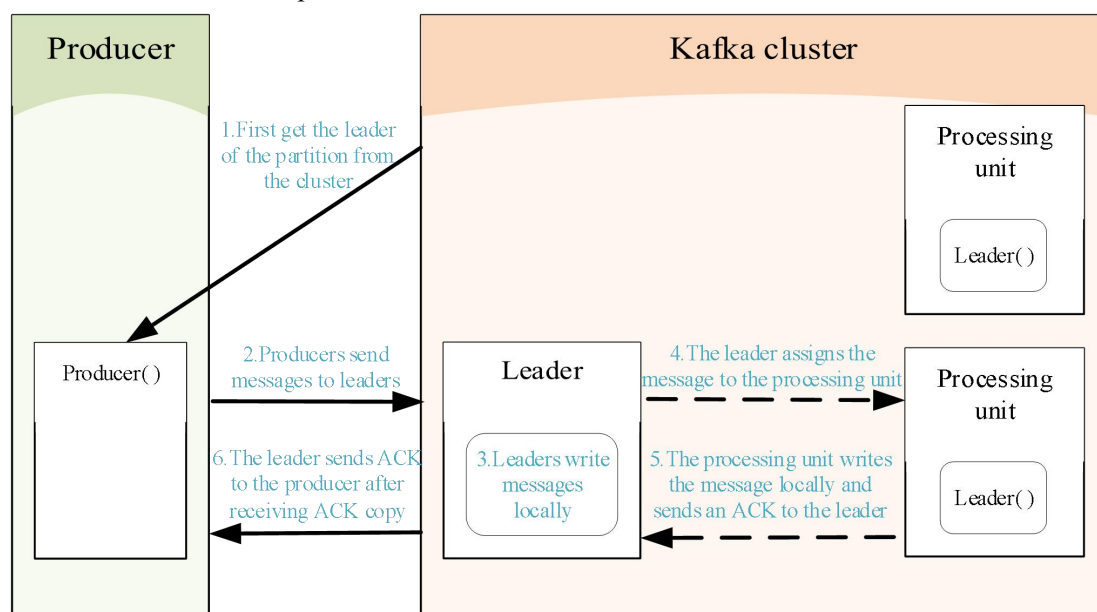

Figure 3. Kafka Processing Flow.

3.4 Data Storage Design

In addition to MongoDB and Redis databases that collect data for storage, it is necessary to install SQL Server to store data. The platform closely focuses users, equipment and projects to realize the storage function. It mainly includes the following contents:

1) User Information table: Each user has basic user name, password and authority. Users can manage the contents of different modules according to different authorities. As shown in Table 2.

2) Equipment Information table: it records the basic information of equipment to facilitate real-time management of the equipment. As shown in Table 3.

3) Project Information table: it records the basic information of project to facilitate real-time progress management of the project. As shown in Table 4.

Table 2. User Information Table.

Fields	Data Type	Description
uid	int	uid
account	varchar	Account Number
pws	varchar	Password

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user_name	varchar	User Name
phone	varchar	Phone Number
role_id	varchar	Role ID

Table 3. Equipment Information Table.

Fields	Data Type	Description
tbm ID	int	Shield Machine ID
Tbm Code	varchar	Shield Machine Number
Tbm name	varchar	Name of Shield Machine
ManageNo	varchar	Management Number
Manufacturer	varchar	Manufacturer
FactoryNumber	varchar	Factory Number
Specification	varchar	Specification
Model	varchar	Model
FactoryDate	varchar	Date of Manufacture
Tbm Vest	varchar	Ownership of Assets
Tbm State	varchar	Running Status
Emp name	varchar	Equipment Manager
Emp phone	varchar	Contact Information
TBMTypeName	varchar	Equipment Type
TBMia	varchar	Equipment Diameter

Table 4. Project Information Table.

Fields	Data Type	Description
Pro ID	int	Project ID
Pro Code	varchar	Project Number
Pro Name	varchar	Project Name
Province	varchar	Project province
City	varchar	Project city
Unit	varchar	Contractor
Emp Name	varchar	Project Manager
Emp Phone	varchar	Contact Information
RingWidth	varchar	Ring Width
Pro State	varchar	Status
ReleaseState	int	Published or not

3.5 Data Security

Data security is the cornerstone of information system building and the primary goal of information system protection. Data security runs through the architecture design of the whole system, from data acquisition, transmission, receiving, storage and access [13]. The data security architecture is shown in Figure 4.

1) Data acquisition stage: the acquisition software of the ground monitoring system adopts a dual-network segment design to isolate the data acquisition from the external network, and the project data and non-machine data are entered through specific software to ensure the operation safety and

data security in the data acquisition process.

2) Data transmission stage: HTTPS is used as the transmission protocol, and the data is encrypted through a specific encryption method to prevent data leakage or tampering.

3) Data receiving stage: a firewall is constructed between that server and the wide area network to protect the data transmission security. After the data transmitted by the client is received, the correct data format is obtained by decrypting the data transmitted by the client.

4) Data storage stage: after the data is decrypted, it is stored in the corresponding database through the intranet, and the server regularly backs up such data stored in the database.

5) Data access stage: it provides users with CRUD service, query service, transaction management, concurrent processing, data context (integrating all responsibilities), etc.
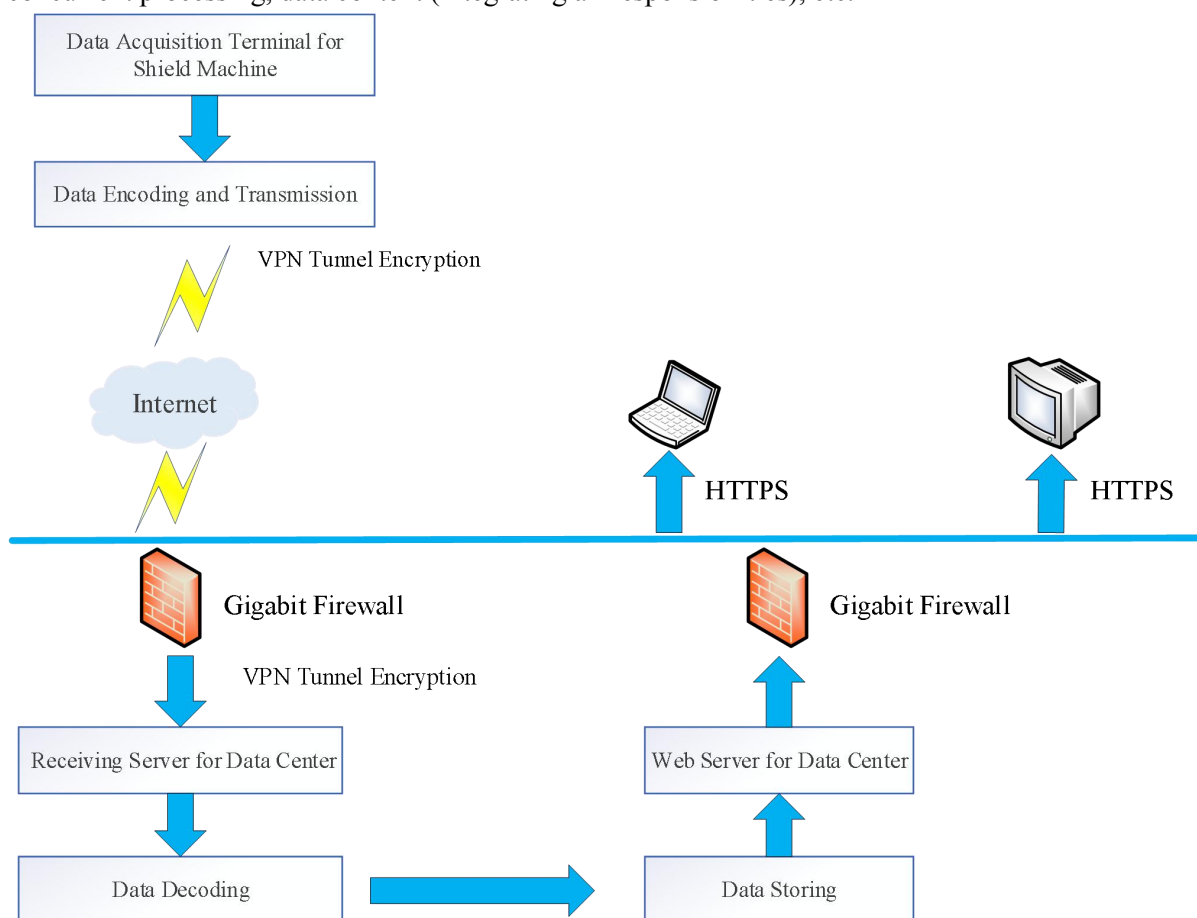

Figure 4. Data Security Architecture.

4. Platform function design and application

4.1 Centralized Monitoring

Centralized monitoring is the real-time monitoring and management for the construction status of different companies and types of shield machines, and also analyzes companies and projects in different dimensions, such as equipment statistics, status statistics, engineering statistics, risk statistics and project analysis, as shown in Figure 5.
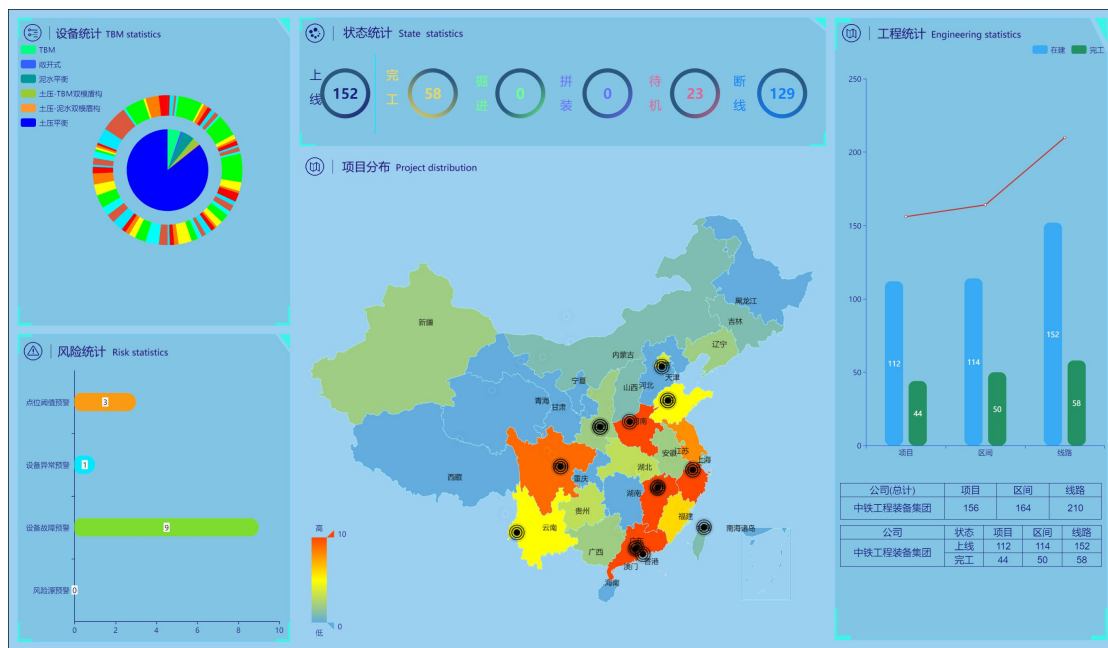
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Figure 5. Interface for Centralized Monitoring.

4.2 Multiple-terminal Access

The platform monitoring information includes tunneling status, construction progress, key parameters, project information, communication status, etc. In order to facilitate different users, the platform designs multi-terminal access such as WEB and App.

Due to the differences in monitoring contents of shield machines, corresponding interfaces are designed for shield machines with different specifications and models at the WEB terminal. Taking the earth pressure balance shield as an example, real-time data monitoring interface includes "main interface", "guide system", "motor drive system", "foam system", "propulsion system", "cumulant interface", "auxiliary system" and "grease system". The main interface is shown in Figure 6.
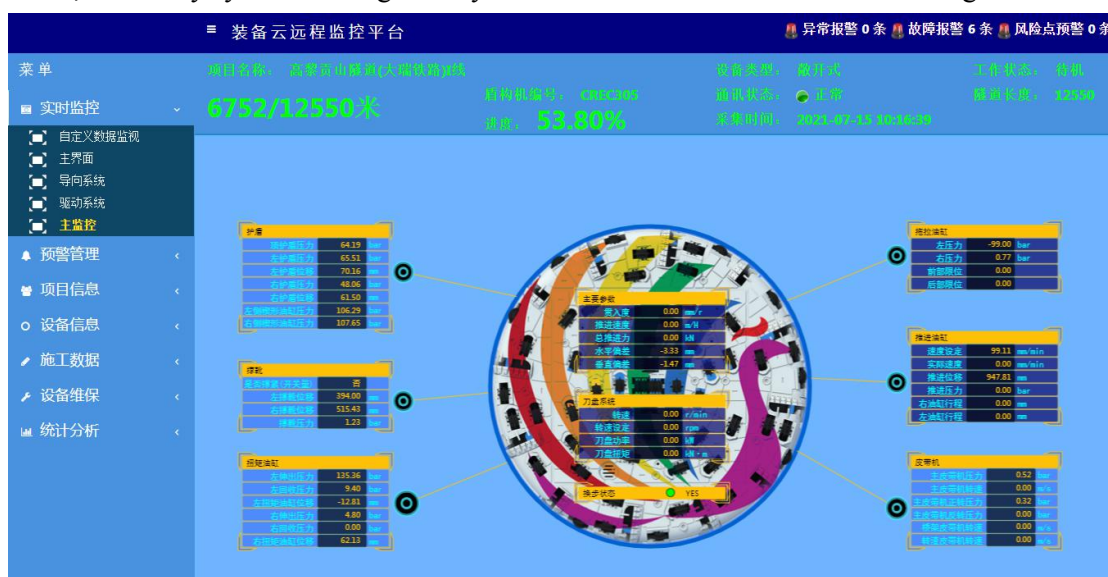

Figure 6. Interface for Real-time Data Monitoring.

In order to view real-time monitoring data for users, the APP terminal functions include project statistics, status statistics, disconnection statistics, warning alarm and real-time data monitoring, as shown in Figure 7.

Figure 7. Interface for APP terminal.

4.3 Collaborative Management

Collaborative management is mainly divided into system management, construction management, risk management, equipment management, which meets the business logic of equipment in the project construction process. The data source is the historical data stored in the big data cluster of shield construction and the business data stored in the business database. Collaborative Management Architecture is shown in Figures 8.
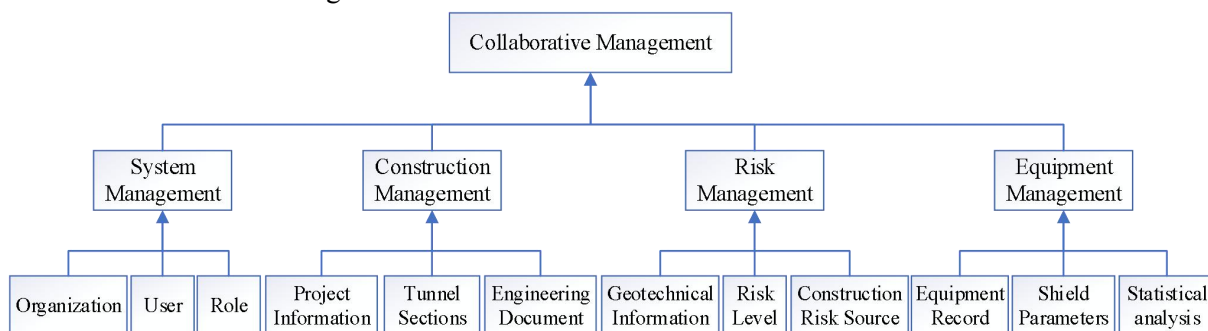

Figure 8. Collaborative Management Architecture.

System management mainly includes organization management, user management and role management. Through system management, the division of tasks can be clearly defined, the management process can be refined, the workload of managers can be reduced, and the management level can be improved.

Construction management mainly includes project information management, drawing of tunnel sections and project document management. Through the entry of construction information and design axis, the construction progress can be better known, the construction quality can be improved, and the reference for project resource allocation can be provided.

Risk management mainly includes geotechnical management, risk levels and construction risk sources. By identifying security risks in advance, inputting risk source information, determining risk level and pushing step by step, the risk control system is established to reduce security risks and improve construction safety.

Equipment management mainly includes equipment record, shield parameters and statistical analysis. Through the inductive reasoning of equipment information, standardized management of equipment is carried out to maximize the value and efficacy of equipment. Interface for statistical analysis is shown in Figures 9.

Figure 9. Interface for Statistical Analysis.

5. Conclusion and Outlook

Aiming at the technical problems of project cluster construction, an intelligent cluster management platform for shield machines is designed, which integrates the functions of multi-project centralized monitoring, multi-terminal access and collaborative management, providing guidance and support for the construction of similar platforms, and data support and application attempts for big data analysis of tunnel construction.

At present, the monitoring data of shield machine are mainly used for equipment alarm, progress analysis, log recording, integrated display. However, due to the complexity of shield machine system, high failure rate, and huge economic loss, the large-scale application of collected data needs to be improved urgently. It is the future development direction to realize the intelligent management of the whole life cycle of shield machine by combining automatic detection, automatic deviation correction, fault early warning, cutter head wear, oil monitoring, land subsidence early warning and advanced geological prediction.

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Acknowledgments

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