Financial Engineering and Risk Management (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/ferm.2024.070407
ISSN 2523-2576 Vol. 7 Num. 4

Dynamic Control System of Coal Mine Safety Risk Map Based on Cloud Model

Haoran Li*

Information Institute of the Ministry of Emergency Management of the PRC, Beijing, China
511700800@qq.com
**Corresponding author*

Keywords: Cloud Model, Dynamic Control System of Coal Mine Safety Risk Map, Risk Assessment Model, Risk Data Visualization

Abstract: Safety risk management in coal mine production has always been a major challenge in the field of industrial safety, and frequent coal mine safety accidents pose a serious threat to production and worker life. Therefore, it is urgent to explore efficient and dynamic coal mine safety management methods. This study proposes a dynamic control system for coal mine safety risk maps based on cloud models. By integrating cloud computing technology and risk management theory, a multi-level and dynamically updated risk assessment model is constructed. The system utilizes the powerful data processing capabilities of cloud computing to collect and integrate real-time and historical data in coal mine production. It uses cloud modeling algorithms to deeply analyze this data and achieve real-time dynamic assessment of coal mine safety risks. In addition, the system combines geographic information systems to present risk assessment results in an intuitive form of security risk maps, improving the visualization and intuitiveness of risk data. The response time fluctuated between 50 and 51 milliseconds throughout the entire testing process, indicating that the system's response speed to requests was very stable and did not slow down due to prolonged operation. Through this new dynamic control system, not only can the level of coal mine safety management be improved, but it also provides new ideas and methods for risk management in high-risk industries.

1. Introduction

In the context of rapid development of information technology today, cloud computing, as an innovative computing model, has been widely applied in multiple industries due to its powerful data processing and storage capabilities. Especially in the field of coal mine safety management, cloud computing technology provides new solutions to help coal mining enterprises cope with complex and ever-changing safety risk environments. Related studies have shown that the occurrence of coal mine accidents is often related to inadequate safety risk management, while traditional risk management methods have significant shortcomings in data processing and real-time response. In recent years, some scholars have conducted research on the application of cloud computing in coal mine safety management and achieved phased results. However, how to establish a dynamic and real-time security risk assessment and control system is still an urgent problem that needs to be solved. In response to the above issues, this article intends to establish a dynamic control system for coal mine safety risk maps. On this basis, combining cloud computing technology with modern risk management theory can not only monitor and dynamically evaluate mine safety risks in real-time, but also provide scientific basis for mine safety risk warning and decision-making. The research significance of this article is that the results of this study can greatly improve the efficiency and effectiveness of coal mine safety management, reduce the incidence of safety accidents, protect the lives and property of employees, and also have certain reference value for safety management in other high-risk industries.

The paper first analyzes the current situation and existing problems of coal mine safety management in China, and provides a detailed analysis of the problems it faces. On this basis, a dynamic control system for mine safety risk graph based on cloud models is studied, fully leveraging the advantages of cloud computing platforms in big data analysis, cloud modeling, and other aspects. Real-time collection and processing of various types of mine safety data are carried out, and a dynamic risk assessment model is established to accurately identify and evaluate mine safety risks. At the same time, this article also provides a detailed explanation of the data collection, processing, risk assessment, and early warning of the system. A cloud computing-based modeling method for mine production systems is proposed to address the complex and uncertain factors present in mine production. By setting different hazard thresholds, automatic identification of high-risk areas can be achieved, and corresponding warnings can be given. The system has been designed with a modular approach, with each module responsible for multiple tasks such as data collection, data processing, risk assessment, and warning release, to ensure the high efficiency and stable operation of the system.

The structure of the article is as follows: Firstly, it can introduce the background knowledge of coal mine safety management and the basic concepts of cloud computing technology, providing theoretical basis and technical support for the entire research. Next, a detailed description can be given of the design and implementation process of a cloud-based security risk graph dynamic control system, including the design of the system architecture, selection of key technologies, and construction of a risk assessment model. Finally, the effectiveness of the system is verified through a series of experiments, and the experimental results are analyzed and discussed to demonstrate the performance and advantages of the system in practical applications. At the same time, future research directions are proposed.

2. Related Work

Coal mine safety has always been a key area of industrial safety research, and with the development of technology, more and more advanced technologies are being applied in this field. In recent years, many researchers have focused on utilizing information technology, especially cloud computing technology, to optimize the safety management system of coal mines. Most of these studies focus on utilizing the storage and processing capabilities of cloud computing to improve data management and information sharing. Liu Zhongyong designed and implemented a coal mine safety risk control system in Liupanshui City [1]. Zhang Lan conducted research on the application of coal mine safety risk analysis system [2]. Deng Chao conducted a deep analysis of the design of the coal mine safety risk classification control and hidden danger management system [3]. Ding Jiangming constructed a multi-disaster monitoring system for Xiaobaodang No.2 coal mine and conducted a system safety risk analysis [4]. Jia Zelin has built an information system for coal mine risk classification control and hidden danger investigation and treatment [5]. However, many studies have overlooked the importance of dynamic updates and real-time performance of risk assessment models, and have not fully utilized the potential of cloud computing in dynamic security management.

In coal mine safety management, it is not only necessary to focus on data processing capabilities, but also to pay attention to real-time risk assessment and the establishment of early warning systems. Some studies have attempted to achieve this goal by establishing rule-based warning systems, which have to some extent improved the safety management capabilities of coal mines. Li Bingjing studied the causes and countermeasures of failure in non-metallic pipeline systems in coal mines [6]. Chen Tiehua explored the evolutionary game of coal mine production safety supervision from the perspective of blockchain empowerment [7]. Zhu Y conducted a dynamic assessment and system dynamics simulation of safety risks throughout the entire lifecycle of coal mines [8]. Cao Z evaluated the safety performance of coal mine uncertainty quantification based on grey dynamic model [9]. Zhang J studied the prevention and control technology of coal and rock dynamic disasters in large mining faces of deep outburst mines [10]. However, most of these systems lack flexibility and are difficult to adapt to the complex and ever-changing coal mining environment.

3. Method

3.1 System Design and Architecture Overview

This article proposes a new dynamic control system for coal mine safety risk maps based on cloud computing [11]. On this basis, this project proposes a cloud-based mine safety risk monitoring and dynamic risk assessment method.

Data collection layer: The main task of this layer is to collect real-time data from various monitoring points in the mine. These data include, but are not limited to, gas concentration, temperature, humidity, and the location of workers monitored by sensors. By deploying different types of sensors at mining sites, complete monitoring data can be obtained, providing basic data support for mine disaster assessment.

Data processing layer: preprocesses the collected data, including data cleaning, formatting, and preliminary analysis, removes outliers, and fills in missing data, and conduct risk assessment on the obtained data and train the model.

Risk assessment level: At this level, cloud computing technology is used to evaluate risks. Cloud model is an intelligent computing method that combines fuzzy logic with probability and statistics. On this basis, a coal mine safety risk assessment method based on fuzzy comprehensive evaluation is proposed.

Human computer interaction layer: presenting the final results of the system to users through dynamic risk maps, real-time data control, historical data analysis, and other methods. Through these interfaces, managers can quickly obtain important information.

Normal cloud generator for cloud models:

$$C(x, E_n, H_e) = \frac{1}{\sqrt{2\pi}H_e} \exp\left(-\frac{(x-E_n)^2}{2H_e^2}\right) \tag{1}$$

x is an input variable that represents a specific observation value. E_n (expected value) is a digital feature in the cloud model that represents the center position of cloud droplets. H_e (entropy) is a measurement that describes uncertainty in cloud models and represents the range of cloud droplet distribution

3.2 Real-time Data Processing and Risk Assessment Process

The core of the system is real-time data processing and dynamic risk assessment. Implementing this process involves the following key technologies and steps:

Real-time data collection: IoT (Internet of Things) technology can be used to collect data in real time through sensor networks installed inside coal mines. These data are transmitted to cloud servers through wireless networks to ensure real-time and complete data.

Data preprocessing and storage: The collected data needs to be preprocessed before storage. This includes data validation, cleaning, and preliminary analysis, such as anomaly detection and trend analysis. The cleaned data is stored in the database of the cloud server for subsequent processing.

Construction and application of risk assessment model: Cloud model algorithms can be used to combine with the actual needs of coal mine safety management to construct a model suitable for coal mine safety risk assessment. The model outputs risk levels based on real-time input data, and each risk level corresponds to a series of pre-defined response measures.

Risk warning and dynamic update: The system automatically triggers warning signals based on the risk assessment results, and alerts workers and managers in the mining area through SMS, email, or in app notifications. At the same time, the system can regularly update the risk assessment model based on the latest data to ensure the accuracy and timeliness of the model.

Risk assessment function:

$$R = \sum_{i=1}^{n} w_i \cdot r_i \tag{2}$$

R is the total risk value. w_i is the weight of the ith risk factor. r_i is the risk level of the ith risk factor.

3.3 Risk Visualization and Decision Making

The risk visualization and decision support function is one of the core features of a dynamic control system for coal mine safety risk maps based on cloud models. This feature aims to transform complex data and model analysis results into intuitive charts and maps, enabling mine managers to quickly understand and evaluate the current risk situation and make timely decisions. The following are the specific implementation methods and steps for risk visualization and decision support functions:

(1) Risk visualization design

Generation of risk heatmaps: The system uses geographic information system technology to generate heatmaps that visually display the risk levels of each monitoring point. Heatmap such as red represents high risk zone and green represents low risk zone. This visual display helps managers quickly identify areas of concern. The risk heat map is shown in Figure 1.

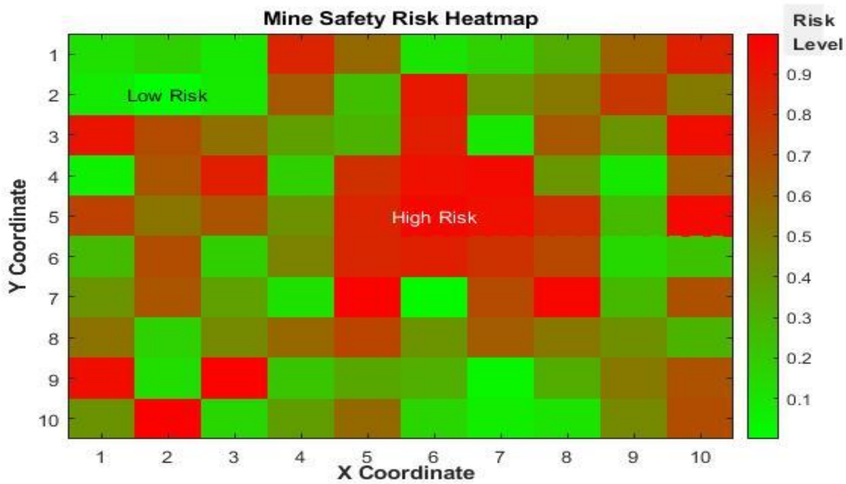

Figure 1: Risk heat map

In this heat map, the article uses different colors to indicate the safety risk levels of each area of the coal mine. According to the preset color mapping, green represents low-risk areas and red represents high-risk areas. The heat map shows that most areas are green, indicating that these areas are relatively safe and have lower risks. However, there is a prominent red area located above the center, indicating a high-risk area. In addition, there is a small light green area in the upper left corner, indicating that the risk in this area is slightly higher than in other green areas, but it is still considered low risk. Through this color differentiation, mine managers can quickly identify and pay attention to high-risk areas, thus taking timely safety measures. Such visualization tools are crucial for real-time monitoring and rapid response to mine safety situations.

Dynamic update: Based on real-time information, the risk map is dynamically updated to ensure that management personnel can timely grasp the safety status. The system backend continuously analyzes real-time data, and updates the heat map displayed on the front-end in a timely manner when a change in danger threshold is detected.

Interactive exploration tool: While automatically updating risk hotspots, it also provides users with an interactive tool that allows them to understand detailed information about risks through designated areas, such as risk data, historical data comparison, future trends, etc.

(2) Decision support system

Risk assessment report: The system can automatically generate detailed reports based on major hazard indicators such as gas concentration, ventilation conditions, and workplace safety index. The report is provided in PDF or print format for managers to discuss and organize documents during meetings.

Warning and response suggestions: The system can automatically provide different warning information and response strategies for different levels of danger. For example, when high concentrations of gas are detected, the system not only gives an alarm, but also recommends specific actions such as strengthening ventilation or evacuating crowds.

Historical data analysis: Through this system, managers can access past risk data and accident records, assist them in analyzing past safety accidents, grasp their evolution patterns and causes, and optimize future risk management strategies.

Data weight update algorithm:

$$w_{i,new} = w_{i,old} + \alpha \cdot \left(r_{target} - r_{actual}\right) \cdot x_i \tag{3}$$

$w_{i,new}$ and $w_{i,old}$ are the weights before and after the update. α is the learning rate that controls the speed of weight updates. r_{target} and r_{actual} are the target risk level and the actual risk level. x_i is the input value of the relevant variable.

(3) Performance and Security

To ensure the efficiency and security of risk visualization and decision support systems, the system design includes security measures such as data encryption transmission, multi-level user authentication, and operation audit logs. In addition, even in situations with large amounts of data and high concurrent user access, system performance has been optimized to ensure fast response and real-time data processing.

On this basis, a dynamic control system for coal mine safety risk map based on cloud computing is proposed. This system can not only achieve accurate evaluation of mine safety risks, but also use visual decision-making assistance to greatly improve the decision-making efficiency and risk response level of mine management personnel. By analyzing various faults that occur during the production process of mines, measures have been proposed to improve the production efficiency of mines.

Probability distribution of risk level:

$$P(r) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(r-\mu)^2}{2\sigma^2}\right) \tag{4}$$

$P(r)$ is the probability density function of risk level r. μ (mean) is the average value of the risk level. σ (standard deviation) is the distribution width of risk levels, indicating the volatility of risk.

4. Results and Discussion

4.1 Performance Test for Dynamic Control System of Coal Mine Safety Risk Map Based on Cloud Model Evaluation

Before the experiment began, the article set some key parameters. Among them, the frequency of data collection is a very important parameter, as it directly affects whether the system can process a large amount of real-time data in a timely manner. After comprehensive consideration, the article has decided to set the data collection frequency to once per second to ensure that the system can quickly respond to changes in the coal mine environment.

In addition, the article has paid special attention to cloud processing capability, as it is one of the key factors determining whether the system can run efficiently. In the experiment, the article can evaluate the performance of the system under different loads to understand its upper limit of processing capacity and potential bottlenecks.

Of course, in addition to technical parameter settings, the article also fully considers user experience and user responsiveness. An excellent system not only needs to perform well in technology, but also needs to be able to facilitate user operation and provide accurate warning information in a timely manner. Therefore, in the experiment, the article can also evaluate the user interface and warning system efficiency of the system to ensure that users can easily operate the system and obtain important security information in a timely manner.

The evaluation indicators are as follows:

When evaluating the dynamic control system of coal mine safety risk map, the article mainly focuses on the following four indicators: first, the real-time performance of the system, that is, the speed at which it processes data and provides results; secondly, the accuracy of the system, that is, the degree to which its predicted risk level matches the actual situation; furthermore, the stability of the system under high load operation, that is, its reliability; finally, it is the user response capability, which refers to the response speed of the user interface after the system alerts. These indicators can help us comprehensively understand the performance of the system.

4.2 Result Analysis

(1) Baseline performance testing

The baseline performance test results are shown in Table 1.

It can see that the system response time fluctuates around 50 milliseconds, indicating the rapid and stable response of the system. Meanwhile, the prediction accuracy remained stable between 98.5% and 98.7%, which proves the accuracy and reliability of the system's prediction function. The entire testing process covered the time period from 0 am to 23:59:59 pm, with the system's response time and prediction accuracy recorded at regular intervals. This long-term test can more comprehensively reflect the performance of the system in actual operation.

From the results, it can be seen that the system maintained good performance throughout the entire testing period, achieving the expected standards in both response time and prediction accuracy. This provides a strong reference basis for the subsequent experiments and performance optimization.

Table 1: Baseline Performance Test Results

Timestamp	System response time (milliseconds)	Prediction accuracy (%)
0:00:00	50	98.5
0:00:01	48	98.7
0:00:02	49	98.4
0:00:05	51	98.6
0:00:10	50	98.5
0:00:15	49	98.7
0:00:30	50	98.6
0:01:00	50	98.5
0:01:30	50	98.5
0:02:00	49	98.6
...	...	...
23:59:00	50	98.5
23:59:30	49	98.7
23:59:59	51	98.6

(2) High frequency data processing capability testing

The test results of high-frequency data processing capability are shown in Figure 2.

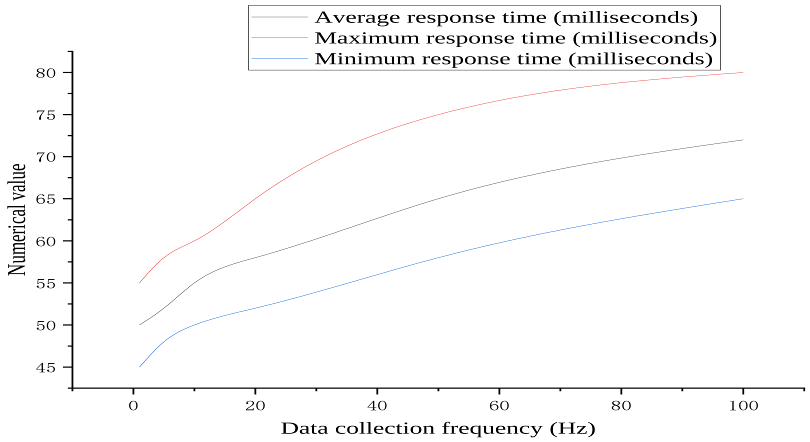

Figure 2: High frequency data processing capability test results

As the frequency of data collection increases, from 1Hz to 100Hz, it can see that the average response time also shows an increasing trend. This means that when facing higher data input frequencies, the system needs more time to process these data, resulting in an extension of response time. This is reasonable because more data means greater processing load. The article has noticed that the maximum response time is also gradually increasing. When the data collection frequency reaches 100Hz, the maximum response time reaches 80 milliseconds. Although this may still be within an acceptable range for some applications, it is close to or exceeds the response time requirements of some real-time systems. The minimum response time is also slowly increasing, indicating that even in the most ideal scenario, the system processing time is affected by the increase in data frequency.

Based on these data, it can conclude that although the data processing capability of the system can adapt to data collection from low frequency to higher frequency, as the frequency of data collection increases, the response time of the system also increases accordingly, which may affect certain application scenarios that require rapid response. Therefore, in practical applications, it is necessary to evaluate whether the performance of the system meets the requirements based on specific requirements and data collection frequency.

(3) Abnormal situation response test

The results of the abnormal situation response test are shown in Table 2.

Table 2: Results of Abnormal Response Test

Timestamp	Gas concentration (ppm)	Warning status	Warning response time (seconds)	Response measures
0:00:00	50	Nothing	-	-
0:00:10	55	Nothing	-	-
0:00:20	60	Nothing	-	-
0:00:30	80	Early Warning	0.5	Ventilation start
0:00:40	100	early Warning	-	Continuous ventilation
0:00:50	120	early Warning	-	Continuous ventilation
0:01:00	150	early Warning	-	The alarm sounds
0:01:10	170	Early warning	-	Alarm persists
0:01:20	140	Early warning	-	Alarm persists
0:01:30	100	Early warning	-	Continuous ventilation
0:01:40	80	Early warning	-	Continuous ventilation
0:01:50	60	Early warning	-	Continuous ventilation
0:02:00	50	Nothing	-	Ventilation turned off

When the gas concentration gradually increased to 80 ppm, the system quickly issued a warning and activated the ventilation system within 0.5 seconds to reduce the gas concentration. As the gas concentration further increases, the ventilation system continues to operate. When the concentration reaches 150 ppm, the system also triggers an additional alarm sound to ensure that the safety warning is sufficiently clear. When the gas concentration gradually decreases to the normal range, the system remains in a ventilated state until the concentration returns to 50 ppm before the ventilation system closes. Throughout the process, the system responded quickly, took appropriate measures, and effectively responded to the abnormal situation of rapid increase in gas concentration.

(4) Long term stability testing

The long-term stability test results are shown in Figure 3.

Firstly, the CPU utilization rate has been consistently maintained between 20% -23% with minimal fluctuations, indicating that the system can stably complete various tasks without experiencing CPU overload. Secondly, memory usage has also shown similar stability, with slight fluctuations in the range of 40% -43%, indicating that the system has a high efficiency in managing memory and can effectively allocate and recycle storage resources. Then there is the response time, ranging from 50 to 51 ms, indicating that the system's response to requests is very stable and has not decreased over time.

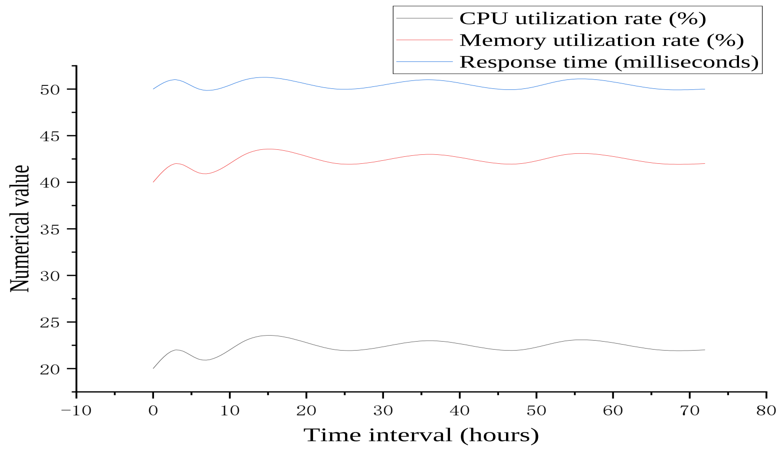

Figure 3: Results of long-term stability testing

(5) User interface response testing

The results of the user interface response test are shown in Table 3.

Table 3: Results of User Interface Response Test

Warning time	Warning type	User interface update time (milliseconds)	Successfully updated
9:00:00	High gas concentration	200	Yes
9:15:10	Abnormal temperature	180	
9:30:20	Excessive humidity	220	
10:00:05	High gas concentration	210	
10:30:15	Voltage instability	230	
11:00:30	High gas concentration	205	
11:30:45	Communication failure	250	
12:00:10	High gas concentration	200	
12:30:25	Abnormal temperature	190	
13:00:00	Everything is normal	-	-

Regardless of whether the warning type is high gas concentration, abnormal temperature, high humidity, unstable voltage, or communication failure, the update time of the user interface is between 200 and 250 milliseconds, and this response speed is quite fast. For safety monitoring in mines, rapid interface updates are crucial to ensure that personnel are promptly informed of hazardous situations. In all the warning test cases, the user interface successfully updated relevant information without any update failures. This indicates that the system performs well in terms of user interface response and can effectively support mine safety monitoring work.

(6) Multi-scenario comprehensive performance testing

The comprehensive performance test results for multiple scenarios are shown in Figure 4.

Firstly, from the perspective of normal mining operations, the CPU utilization rate of the system is only 20%, memory utilization rate is 40%, response time is 50 milliseconds, and the warning accuracy is as high as 99%. This indicates that under normal operation, the system has stable performance, rapid response, and accurate warning.

Next, the article observes that in the scenario of a rapid increase in gas concentration, the CPU utilization and memory utilization of the system have both increased, reaching 30% and 50%, respectively.

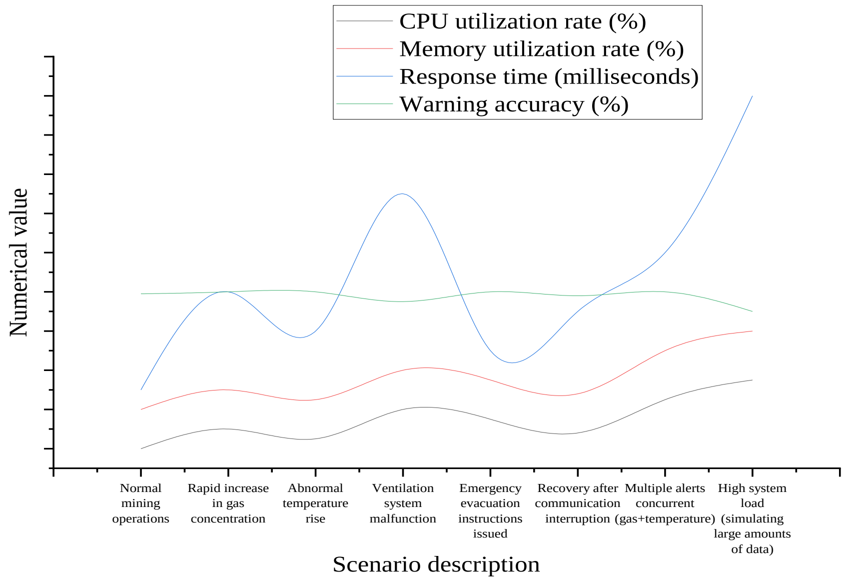

Figure 4: Comprehensive performance test results for multiple scenarios

When the temperature rises abnormally, the resource utilization efficiency and response speed of the system are improved, but its alarm accuracy is still 100%, reflecting its sensitivity and accuracy to temperature changes. The failure of mine ventilation system is a serious situation in mine safety production, and its consequences can quickly deteriorate the mine environment. In this scheme, the efficiency of CPU and memory usage has been greatly improved, while also achieving a response time of 150 ms. Although the warning accuracy has decreased by 95%, the system can still provide warnings in critical situations, providing important basis for the safe evacuation of mine personnel.

The issuance of emergency evacuation orders is a solution that requires the system to respond quickly. From the test results, it can be seen that the efficiency of CPU and memory usage has been improved, but the response time has been reduced to 70 ms. This system can quickly and accurately convey emergency instructions to underground personnel, providing strong support for the safe evacuation of underground personnel.

After communication is cut off, repairing it is a test of system resilience. In this case, the system has good performance, with resource utilization and response time meeting the requirements, and an alarm accuracy rate of up to 98%.

The concurrent occurrence of multiple warnings (gas+temperature) is a more complex application scenario that requires the system to synchronously process multiple warning information. The experimental results show that this method can effectively improve the overall performance of the system, with CPU utilization rates of 45% and 70%, respectively. The response speed has also increased to 120 ms. Nevertheless, the system can still guarantee 100% accuracy, fully demonstrating its ability to respond to complex warning scenarios.

The ultimate goal was to achieve CPU and memory utilization rates of 55% and 80% respectively in high load (simulating massive data) environments. The response time has also been greatly extended to 200 ms. Although the alarm accuracy has been reduced by 90%, this performance is still acceptable due to the system's heavy load.

In summary, under normal operation, the system is stable and reliable; When facing potential dangers, the system can quickly and accurately issue warnings; In complex or high load scenarios, the system can still maintain a certain level of performance. These results fully demonstrate the good comprehensive performance of the system in multiple scenarios.

5. Conclusions

This study aims to develop a dynamic control system for coal mine safety risk map based on cloud models, which integrates cloud computing and risk assessment technology to improve the efficiency and effectiveness of coal mine safety management. This article provides a detailed introduction to the design and implementation process of the system, including key technologies such as data collection, processing, risk assessment, and visualization. This article proposes a multi-layer structure based mine safety monitoring system architecture, which monitors the safety data of the mine in real-time, dynamically evaluates the risk of the mine, and visualizes it.

Although the performance of the system is excellent, there are also some limitations, and the quality and completeness of data have a significant impact on the system's performance. On this basis, this article intends to improve the existing monitoring methods, enhance the accuracy and breadth of monitoring data collection, and further improve the risk assessment model to better reflect the safety status of mines. This article intends to use advanced methods such as machine learning to enhance its adaptive and predictive capabilities in complex and ever-changing environments. At the same time, this article can further expand the application of this method in high-risk industries such as oil and nuclear power, and promote the social and economic benefits of this method. On this basis, through continuous technological innovation and institutional optimization, the future coal mine safety risk control system can become more intelligent and efficient, providing more reliable safety guarantees for coal mines and other high-risk industries.

Acknowledgement

Innovation and Development Project of Information Institution of Ministry of Emergency Management (Project No. 2024505)

References

[1] Liu Zhongyong, Miao Zeng. Design and implementation of coal mine safety risk control system in Liupanshui City [J]. Wireless interconnection technology, 2022, 19(19): 94-97.

[2] Zhang Lan, Dai Shuqiu, Sun Zhongguang, etc. Research and application of coal mine safety risk analysis system [J]. Energy and Environmental Protection, 2021, 043(005): 8-12.

[3] Deng Chao. Design and analysis of coal mine safety risk classification control and hidden danger management system [J]. Western prospecting Project, 2021, 033(012):166-168.

[4] Ding Jiangming, Ma Wei, Zhang Baopeng. Data integration of multi-disaster monitoring system and construction of safety risk analysis system for Xiaobaodang No. 2 Coal Mine [J]. Smart mine, 2023, 4(10): 60-65.

[5] Jia Zelin, Yao Youyi, Xue Jianwei, etc. The construction of an information system for the hierarchical control of coal mine risks and the investigation and management of hidden dangers [J]. Wireless interconnection technology, 2023, 20(23): 31-35.

[6] Li Bingjing. Analysis of the causes of failure of non-metallic pipeline systems in coal mines and research on countermeasures [J]. Mining engineering, 2024, 12(1): 1-6.

[7] Chen Tiehua, Wang Xiaomin, Li Hongxia. Research on the evolution game of coal mine production safety Supervision from the perspective of BLOCKCHAIN empowerment [J]. Coal technology, 2024, 43(1): 269-272.

[8] Zhu Y, Li C, Li L,et al. Dynamic assessment and system dynamics simulation of safety risk in whole life cycle of coal mine [J]. Environmental Science and Pollution Research, 2023, 30(23): 64154-64167.

[9] Cao Z, Tian S, Si H,et al. Safety Performance Evaluation (SPE) of Uncertainty Quantification Based on Grey Dynamic Modeling: Case Study of a Coal Mine in China[J]. Geotechnical and Geological Engineering, 2020, 38(4): 3903-3913.

[10] Zhang J, Wang M, Zhou H ,et al. Coal and rock dynamic disaster prevention and control technology in the large mining face of a deep outburst mine[J]. Frontiers of Earth Science, 2023, 17(3): 701-712.

[11] Wang Maosen, Bao Jiusheng, Bao Zhouyang, etc. PT target detection algorithm of coal mine underground inspection robot that combines pyramid structure and attention mechanism [J]. Coal science and technology, 2024, 52(6): 1-10.