Research Article
Safety Technology Risks and Countermeasures in the Intelligent Construction of Coal Mines

Jinyan Bai,1 Dezhi Zheng,2,3 and Chen Jia4

1China Coal Technology & Engineering Group Corp, Beijing 100013, China
2China Coal Research Institute, Beijing 100013, China
3School of Public Policy and Management, China University of Mining and Technology, Xuzhou, Jiangsu 221008, China
4Organ Affairs Bureau of Ministry of Emergency Management, PRC, Beijing 100054, China

Correspondence should be addressed to Dezhi Zheng; zhengdezhi@mtghy.com

Received 22 April 2022; Accepted 13 May 2022; Published 26 May 2022

1. Introduction

Although the proportion of coal in China’s energy consumption structure continues to decline, its proportion was still about 60% in 2020. It can be seen that coal is still an important cornerstone in ensuring the security of China’s energy supply [1, 2]. Under the goal of carbon neutrality, it is necessary to accelerate the transition of China’s energy consumption structure to green energy, and the proportion of nonfossil energy consumption needs to increase significantly [3–6]. The evolution process of China’s energy consumption structure from 2015 to 2020 is shown in Figure 1. The process of coal development and utilization will inevitably cause damage to the environment and have negative environmental and ecological effects. Through the deep integration of modern information technology and the coal industry, the transformation, upgrading, and high-quality development of the coal industry can be realized [7–10]. In the past 10 years, the coal industry has made a number of key breakthroughs in the innovation and R & D of intelligent mining technology, and mining equipment, modern intelligent, green, safe, clean, and efficient modern coal mines have been built, laying a solid foundation for the transformation and high-quality development of China’s coal industry [11–17].

The deep integration of the coal industry and the new generation of information and communication technology has achieved remarkable results in the fully mechanized intelligent unmanned mining technology of coal mines. Fully mechanized intelligent unmanned mining technology refers to the safe and efficient mining technology that is equipped with hydraulic support, a shearer, a scraper conveyor, and other fully mechanized mining equipment with sensing, memory, learning, and decision-making abilities. It uses an automatic control system as a hub and visual remote monitoring as a means to realize the “unmanned operation and safe patrol” in the process of fully mechanized
At present, China Coal Energy, Shandong Energy, Jinning Holding, and other enterprises are actively carrying out intelligent construction. By the end of 2021, there were 687 intelligent mining faces in China, including 431 intelligent mining faces and 256 intelligent excavation faces, reducing the number of people and increasing efficiency in the mine and achieving good application results. In September 2014, the Huangling No. 1 coal mine realized the fully mechanized, intelligent mining face of a medium thick coal seam, with an annual output of 4 million tons. It took the lead in realizing the normalization of surface remote control coal mining in China. In August 2016, the 23,303 working faces of the Zhuanlongwan coal mine realized an RSS full working face following automation and LASC automatic alignment, achieving a high accuracy and the expected effects. In 2018, the Zhangjiamao and Balasu coal mines carried out an intelligent transformation of production mines and the intelligent design of new mines, thus solving the problem of a lack of intelligent decision-making through the construction of intelligent mine management and a control platform. Intelligent coal mine construction for Heidaigou, Shangwan, and six other coal mines has received provincial acceptance.

Coal mine intelligence is the core technical support for the high-quality development of China’s coal industry, which enjoys a broad consensus in the industry and is inseparable from technology development, top-level policy design, and the coordinated promotion of the industry. At present, with the continuous acceleration of the process of China’s intelligent coal mine construction and the continuous improvement in the degree of coal mine intelligence, intelligent coal mine construction has become a basic condition for the approval of coal mines, a basic requirement of construction and operation, and an important aspect of safety supervision. Intelligent construction has become an effective means to reduce personnel, improve efficiency, and improve the occupational environment. However, it has also brought new safety risks and technical challenges to mine safety at many levels. This paper summarizes the development process of intelligent coal mine construction in China and describes the safety risks and technical challenges that intelligent coal mine construction may bring to the safety of coal mine production.

2. Materials and Methods

Faced with complex geological conditions, natural disasters, and difficult mining and frequent accidents in China’s coal mines, China has continued to steadily promote the construction of safe and efficient mines and modern mines, has reformed coal mining technology, and has gradually improved the safety of coal mine production conditions, and the mortality rate per million tons has decreased year by year. The evolution trend of China’s raw coal production and million-ton mortality is shown in Figure 2. Generally speaking, the development process of coal mine safety in China is divided into three major periods: the period from 1949 to 1977 is a period of sharp fluctuation, the period from 1978 to 2002 is a period of continuous improvement, and the period from 2003 to 2020 is a period of rapid improvement. The improvement in production safety in the coal industry year by year is inseparable from the comprehensive safety management and the overcapacity elimination measures implemented by the state, as well as the policy guidance of the state to accelerate the construction of mine informatization and intelligence.

By analyzing the development process of China’s intelligent coal mine construction, it can be concluded that China’s coal resource mining has mainly experienced four stages (Figure 3): manual mining from 1949 to 1959, blasting mining from 1960 to 1966, a transition from general mining to mechanized mining from 1967 to 2000, and a gradual
transition from automatic mining to intelligent mining since 2001. In the stage of manual mining and blasting mining, the core task of China’s coal industry was to ensure coal production and supply. The coal mines built were mainly small- and medium-sized, and the coal mine production technology and equipment were relatively backward, resulting in frequent coal mine accidents. The mortality rate per million tons fluctuated between 4.32 and 22.28, and production was severely unsafe. With the development of coal equipment preparation technology and information technology, China gradually entered the stage of mechanized mining in the 1980s. This stage was a period of continuous improvement in the safety of coal mine production. In this period, the safe and efficient mining of coal mines through technological progress was gradually promoted, and significant progress was made in the construction of large coal bases. The mortality rate per million tons decreased from 9.44 in 1978 to 4.94 in 2002. The overall safety of coal mine production continued to improve steadily. At the beginning of the 21st century, the Xiaoqing mine of the Tiefa group introduced the
first coal ploughing unit in China and built the first automatic working face [11]. China’s coal industry thus entered the stage of automatic mining, which ushered in the “golden decade” of coal industry development. Production safety has rapidly improved, investment in production safety by coal mining enterprises has continued to increase, and the degree of coal mining mechanization has been greatly improved. Key technologies and equipment for major disaster management have been popularized and applied, and the mortality per million tons has rapidly decreased from 3.71 in 2003 to 0.058 in 2020.

Since the 12th Five-Year Plan, the intelligent construction of China’s coal mines has made considerable progress, beginning the prelude to the intelligent mining of China’s coal resources [13]. China’s coal industry has gradually entered the stage of intelligent mining, which is gradually realized in stages. The progress from technology to equipment is an important guarantee of the intelligent mining of coal mines. The National Energy Administration and the State Administration of Mine Safety have studied and formulated a guide for intelligent coal mine construction, which states that intelligent coal mines should be based on the construction of an industrial Internet platform, a set of standard system should be adopted, a comprehensive perception network should be built, a high-speed data transmission channel should be built, a big data application center should be formed, and on-demand services for different business departments should be realized. The overall technical framework of intelligent construction in underground coal mines and open-pit coal mines is shown in Figure 4.

3. Results

3.1. Correct Cognition of Intelligent Coal Mine Construction and the Safety Risks. The occurrence mechanism of mine disasters has become extremely complex, prevention and control are more difficult, and coal mine safety is facing severe challenges. Coupled with the three-dimensional distribution of coal mine safety risks in geographical space and the dynamic development in time, disasters such as gas and coal dust explosions, water permeability, fires, and roof and electromechanical accidents are dynamic, random, and fuzzy. As a traditional high-risk industry, coal mines are still severely unsafe, and accidents occur frequently. Although the construction of intelligent coal mines may reduce safety risks, there has not been a breakthrough in coal mining technology and mining methods. In addition, safety risks are an inherent attribute of coal mines. Similarly, with the industrial application of new materials or technologies, there is a lack of effective and reliable monitoring and inspection guarantees, which also leads to unknown safety risks to the intelligent production of coal mines. Therefore, we should strengthen the effective monitoring of coal mines.

From the perspective of information security, security protection objects constituting an intelligent mine system mainly include the equipment, the network, control, data, and the application system. The main factors causing security risks are the internal security of the equipment, the network, control, data, and the application system as well as the system security between the equipment and the network, between the equipment and the control, and between the data and the network. At present, China is still in the primary stage of intelligent mine construction, and there are many technical problems. For example, the communication protocols of intelligent devices are not unified, the intelligent safety monitoring standards are not unified, the environment cannot be fully perceived, the source data collection is not standardized, and the big data analysis and processing capacity is low, which leads to systematic safety violations and bring new safety risks to mine production safety.

Production safety real-time monitoring and daily management data are sources of digital transformation and enterprise upgrades in the future. However, if data is maliciously tampered with, it will also have an irreversible impact on the operation of a production safety system. Although the application of blockchain technology in coal mines in recent years has ensured the reliable transmission of data in terms of data transmission and has effectively prevented malicious tampering, it cannot ensure the authenticity and accuracy of data outside the blockchain in the source collection and input links. The data input in the blockchain only means that the data cannot be tampered with, and the authenticity and accuracy of source data cannot be guaranteed. At the same time, there is no effective mutual inspection and verification mechanism between that data and the source exception data. In the process of intelligent mine construction, if the authenticity and reliability of the data source are ignored, security risks in terms of distortions in the data source and in the business applications of comprehensive intelligent management and control platforms will result, and big data decision analyses and business applications, such as time sequences, object attributes, spatial analysis, and index analysis, will be inaccurate.

In the development process of a mechanization and automation system of mining faces and transportation equipment, there are many problems, such as many single machine systems, a large amount of coordinated operation tasks, different functions, different implementation effects, a lack of consistent safety assurance measures, a lack of standard test methods and inspection means, and a lack of safety performance inspection in multimachine and multisystem linkages, the last of which has become a major risk in the production safety of intelligent mining. For example, in terms of main coal flow transportation, belt conveyor coal flow detection, coal flow foreign matter detection, coal stacking detection, belt surface damage detection, belt conveyor fire monitoring, and inspection robots lack test conditions and lack monitoring and inspection methods. Belt conveyor monitoring system reliability, communication anti-interference, monitoring scope, protection effectiveness, and optimal control lack a means of systematic verification and belt conveyor cluster coordination. Multisystem linkage safety performance inspection is also insufficient, which has become a weakness in the intelligent construction of coal flow transportation.

In intelligent mining process analysis and decision-making, the equipment intelligent sensing of multiperception parameter fusion processing, the intelligent collaborative control of working faces, and intelligent inspection robots
apply new technologies and equipment to intelligent mine construction. Compared with the safety risks caused by complex factors such as humans, machines, materials, and environments in the traditional production mode, the advantages of comprehensive perception, intelligent decision-making, and the automatic execution of intelligent coal mines can effectively reduce safety risks at the production site. At the same time, this leads to instability and performance challenges in the security and unreliability of Internet of Things (IoT) equipment, control system networks, and communication systems. The compatibility and environmental adaptability of a “production control decision communication” multisystem and IoT equipment may induce new systematic production safety risks.

3.2. Technical Challenges Faced by Intelligent Coal Mine Construction. Sensors are data sources in intelligent coal mines. Intelligent sensors can improve the accuracy and reliability of sensor measurement data and improve the maintenance efficiency and operation stability of the equipment and the system. At present, the standards, specifications, technical requirements, and test platforms of coal mine sensors are mostly made for specific parameters, errors, displays, communications, and other basic tasks. With the implementation of intelligent coal mines, in addition to the above basic functions, the intelligent sensors used in coal mines should also have more intelligent functions, such as identity information uploading, fault self-diagnosis, remote maintenance and calibration, self-calibration, self-measurement, local data backup, and disconnection continuous transmission. However, there is still a lack of test and verification methods and verification platforms for the intelligent function of sensors.

For example, the ventilation system is known as the “blood circulation system” of the mine, and it ensures the safe and efficient production of the mine. Therefore, building intelligent ventilation systems is an inevitable trend in mine ventilation development. Environmental gas monitoring data, the measurement and monitoring of roadway air volume, and air volume calculations are the most direct and simple way for coal mines to master the operation state of ventilation systems. Under the background of intelligence, higher requirements are put forward for the accuracy, timeliness, comprehensiveness, and reliability of air volume measurements in mine ventilation. The traditional method of measuring the average wind speed and calculating the air volume of the roadway by using point type wind speed sensors and hand-held wind meters cannot meet the needs of intelligent ventilation. Based on this development trend and the actual needs of users, roadway air volume measurement devices based on different measurement methods have become commercially available, such as automatic mobile mechanisms, UAV flights, multipoint telescopic mechanisms, and the ultrasonic propagation time difference measurements. Because there is no roadway air volume standard device in China, the measurement accuracy of these measurement devices cannot be verified. After the intelligent ventilation system is settled through the air network, it is necessary to adjust the opening and closing size and direction of the on-site air window if necessary, and the adjusted results should also be dynamically fed back to the ventilation network management system platform in real time. The ventilation system involves integration and collaborative application requirements between multiple systems such as “production control decision communication,” aiming at safety and reliability. The detection and inspection standards and requirements of performance indicators will restrict the development of roadway air volume detection and intelligent ventilation technology to a certain extent, affect the construction effect of intelligent mine ventilation, and even lead to potential safety hazards.
Intelligent integrated management and control business applications need to dynamically obtain real and reliable geological survey data, real-time monitoring and monitoring, production safety data, professional business management data, and other information. Various objective or man-made interference factors will be generated in many links, such as data generation, collection, transmission, storage, and display, which will affect the final real acquisition of data. The credibility of data in the process of management and control is the cornerstone of realizing an intelligent collaborative management and control application of coal mine production safety. Intelligent comprehensive management and control must rely on a credibility data link to build an intelligent application system. However, the existing collected data lack the verification and analysis means of data credibility. It is urgent to strengthen the credibility analysis and verification ability of data in the generation, collection, transmission, storage, and display link, according to the business requirements of intelligent comprehensive management and control.

Although some coal mines have carried out the secondary protection of information security technology and information system security protection, which, due to nonstandard management, meets the basic safety protection function of coal mines, network attacks, viruses, Trojans, and blackmail software all bring major hidden dangers to the production safety of coal mines and affect the reliability and stability of the industrial control system. With the overall planning and implementation of intelligent construction in coal mines, due to the existence of the original chimney subsystems, there are great differences in the technical selection, architecture design, and safety protection of each subsystem. Each subsystem has its own independent authentication and access management, including user identity, password, and authorization. However, with the unified login authentication and authority management required by the intelligent integrated management and control platform for each subsystem, the risk of user data leakage in user management and authority distribution increases. At the same time, improper permission control may also lead to data access security problems. With the promotion of the construction of intelligent management and control in coal mines, the number of intelligent mobile terminals is increasing. Coupled with a variety of wearable intelligent equipment and devices, achieving safe interactions in the object human network based on a wireless environment is a major problem that needs to be solved. Nonstandard operation and maintenance, improper authority distribution, and lax network access control can induce production safety accidents. The fragmentation of the IoT ecology and the uncertainty of artificial intelligence leads to new systematic security threats to the safety of coal mine production. At present, human–computer interaction is mainly achieved through password and authentication technology, which ensures the security of the network and information. However, the essential demand of the comprehensive perception and interconnection of all things in the construction of intelligent mines in the coal industry cannot be met only by relying on password and authentication technology. There is an urgent need to build a full scene network security protection system. Only by using technical means and network security strategies such as security interaction, trusted interconnection, and intelligent defense can it be credible and reliable. The link security service of all kinds of object human network interactive business can be reliably guaranteed.

4. Discussion

At present, the development of China’s coal mine intellectualization is still in its infancy, and it faces more severe safety risks and technical challenges. It is urgent to make an overall plan, overcome the key core technology of safety guarantee of series “neck,” strengthen the access analysis and verification of intelligent equipment, strengthen the analysis and verification of data reliability in the construction process, improve the ability of security level protection, and promote artificial intelligence, blockchain, big data, cloud computing, and Internet of things. The deep integration of new technologies, such as intelligent equipment and coal mining technology, steadily promotes the intelligent coal mine construction and plays an important role in realizing the continuous and stable improvement in the safety of coal mine production.

Improvement in the safety of coal mine production is inseparable from scientific and technological innovation in the field of production safety. In recent years, through the innovative research and development of intelligent mining technology and equipment, breakthrough technologies have been established, and important achievements have been made in the fully mechanized intelligent mining of thin coal seams, with large mining heights. At present, a new round of technological revolution and industrial transformation is developing at an accelerated rate. The new generation of information technology is deeply integrated with coal, and digitalized and intelligent equipment systems are gradually being applied. It is important to use big data, cloud computing, IoT, AI technology, and other scientific and technological means to overcome such technical problems as giant intelligent system incompatibilities, the lack of traditional sensor equipment reliability, mining imbalances, digging imbalances, and poor equipment adaptability. The production safety of coal mines must be ensured.

It is important to make full use of the collaborative and joint advantages of scientific and technological resources, e.g., through intelligent coal mine technology innovation alliances. Scientific research institutes, colleges and universities, coal production enterprises, equipment manufacturing enterprises, and information technology enterprises need to unite and build a production learning research application innovation chain, establish breakthrough technologies related to coal mines, build common technology platforms, and accelerate planning, ecological constructions, standard formulations, technology research and development, and equipment manufacturing. The process of application and industrialization as well as intelligent coal mine construction must be promoted. At the same time, special research on the safety of coal mines needs to be carried out to improve the platform security, network security, data security, and application security of coal mines in terms of safety planning,
management systems, procedures and measures, technical means, and strategy formulation.

5. Conclusion

(1) Artificial intelligence, big data, cloud computing, industrial IoT, and other new-generation information technologies are deeply integrated with traditional mining technology to promote the reform of coal mine development. Coal mine intelligence is the core technical support used for the high-quality development of the coal industry and is of great significance for improving coal mine safety risk monitoring, early warning systems, and comprehensive disaster management.

(2) Intelligent coal mine construction in China has made great progress. However, the continuous development of coal mine intelligence, especially the industrial application of new materials and technologies, lacks effective and reliable monitoring and inspection guarantees, which also leads to unknown risks and new technical challenges to coal mine safety. Nonuniform intelligent disaster monitoring standards, nonstandard source data collection, low big data analysis, processing capacity, and other factors can induce systematic safety violations. At the same time, there is a lack of verification and analysis means for the authenticity and credibility of the obtained data.

(3) It is important to promote the intelligent construction of coal mines with technological innovation as the core, support the intelligent perception and control of coal mines with the safety access verification of intelligent equipment, improve the safety of coal mines with new technologies and techniques, make full use of the collaborative advantages of intelligent scientific and technological resources, overcome the key core technology problem of the "neck," and ensure the orderly progress of intelligent coal mine construction.

Data Availability

The datasets generated during the current study are available from the corresponding author on request.

Conflicts of Interest

There is no conflict of interest in the submission of this manuscript, and the manuscript has been approved by all authors for publication.

Acknowledgments

This work was supported by the Strategic Consulting Project of the Chinese Academy of Engineering [2022-XZ-28-1] and through the Modernization of Coal Mine Safety Supervision Capacity and Preparation of the 14th Five-Year Plan.

References


