Reform, application and challenges of utilizing big data in coal mine safety management research

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Abstract: Big data greatly impact current social science research paradigms and traditional safety management. Moreover, widespread big data application in coal mine safety technology has also highlighted the lack of basic coal mine safety management review against the background of big data. Based on the above analysis, the three main article goals are (1) to study the fundamental safety management research changes within the big data context; (2) to analyze big data application in coal mine safety management; and (3) to discuss big data relevance in coal mine safety management development trends and challenges. In summary, integrating big data into coal mine safety management has become a research trend, and the current coal mine safety management theory in the field of big data requires more in-depth research.

1. Introduction

With the rapid development of big data technology and the gradual improvement of the safety management theory, data mining technology has attracted the attention of many scholars and enterprises in the field of safety management decision-making [1],[2]. Facing increasing employee safety demands and public attention, coal mining companies are required to improve their safety management level to adapt to rapid societal development. However, how to accurately and efficiently conduct coal mine enterprise safety management and improve its effectiveness is a safety issue that urgently needs to be resolved by coal mine enterprises.

Informatization and big data have improved the safety management level of coal mine enterprises to a certain extent, but if there is no matching data management capability, safety and efficiency problems will occur [3].Enterprise managers are increasingly facing extensive management object safety data, but they cannot perform in-depth analysis in a timely and effective manner to glean useful knowledge from existing safety big data, thus causing the problem of coal mine safety management information overload. As a result, enterprise managers rely on incomplete safety information knowledge, which leads to ineffective management strategies. Therefore, coal mine safety managers should first understand the relevant state and basic safety data in a timely and accurate manner. (Fig. 1).
2. Reform of coal mine safety management against the background of big data

2.1. Reform of the safety management concept

The emergence of safety problems stems from the contradiction between the growing employee safety needs and the imperfect safety status of enterprises. Safety issues will change with employee safety needs and safety technologies and will also cause corresponding safety management concepts to change [4]. According to existing research on the safety management theory, we divide the safety management theory into four stages according to the time node, namely, the accident cause, traditional safety management, system safety management and big data safety management theory stages (Fig. 2). These four stages do not have independent intervals but overlap and interactions will occur at each stage.

The theory of accident causation mainly regards an accident as the external performance of safety management [5]. Big data-based safety management has the characteristics of accuracy and reasoning, but currently, enterprises do not pay enough attention to safety management data and cannot easily extract data [6]. As shown in Fig. 3, the safety management concept within the big data context should focus more on the analysis of safety management big data. Through analysis of safety management big data, we can find meaningful rules and regulations behind the data to improve the level of safety management. The safety management concept within the big data context should be centered on safety data. Safety management big data should be the starting point, and data mining of extensive safety big data should be conducted to determine the current problems and effective relationships in enterprise
safety management. A concept of safety management is shown in Fig. 3.

![Diagram showing the concept of safety management.]

Fig. 3. Safety management theory from the perspective of big data

2.2. Reform of safety management thinking

Based on current research, big data have caused a sea change in safety thinking. Safety management thinking based on big data is mainly reflected in four aspects: association thinking, dynamic thinking, forward thinking, and data thinking (Fig. 4).

In the traditional era of small data thinking, due to the limited amount of data, people have focused more on causality between data variables [7]. Big data-based safety management thinking is more concentrated on the correlation between data variables. Big data-based safety management thinking is also reflected in dynamic thinking. An enterprise contains much real-time data, and the capacity of these data is very high, which can generate several Gb or even more data per second. Big data have also caused a shift in safety management thinking from reverse thinking to positive thinking. Finally, big data also transform empirical thinking into data thinking in traditional safety management. When faced with a large number of danger sources and hidden dangers, people no longer rely solely on their own safety experience but instead realize the control of safety issues by means of data management and mining.

![Diagram showing the reform of safety management thinking.]

Fig. 4. Safety management thinking with big data

2.3. Reform of safety research methods

With the change in safety management concepts and technology development, safety management research methods are constantly changing. Based on the concepts of different driving methods in the control theory, coal mine safety management research methods are divided into knowledge-driven, model-driven, data-driven, and hybrid-driven methods. The specific ideas are shown in Fig. 5.
We accrued statistics on the specific models, advantages, disadvantages and relevant references of these four safety management research methods, and specific information is summarized in Table 1.

### Table 1 Advantages and disadvantages of the four safety research methods

| Safety approach                | Specific methods                                                                 | Advantage                                      | Disadvantage                                                                 |
|-------------------------------|----------------------------------------------------------------------------------|------------------------------------------------|------------------------------------------------------------------------------|
| Knowledge-driven approach     | Expert systems, the graph theory, and accident trees                             | Quick response to risk factors                 | Limited subjective personal capacity leads to highly subjective analysis    |
| Model-driven approach         | Theoretical model of safety behavior; system security simulation; dynamic safety management | Complete and mature research process           | Overfitting problems and lag in research results                             |
| Data-driven approach          | Classification, clustering, prediction and association methods                   | High-speed information processing and resource-integration capabilities | The heterogeneity and privacy settings of secure big data lead to complex data processing |
| Hybrid-driven approach        | Knowledge-model hybrid-driven, knowledge-data hybrid-driven, and model-data hybrid-driven approaches | The advantages of different models are combined to optimize the security analysis method | Coupling of the different methods requires researchers to establish a comprehensive method theory |

3. **Application of big data technology in coal mine safety management**

With the development of digital and perceptive mines, the ability to obtain safety information has been improved, and the problem of mine safety management information overload has also emerged [8]. Therefore, this section builds the overall framework of coal mine safety production management based on big data to explain the different big data predictions, classifications, analyses and optimizations of coal mine safety production activities and the different coal mine safety management areas at the different stages of the method.
In the face of massive safety data, managers cannot effectively extract valuable safety laws [9]. Therefore, to systematically examine the main role of big data in coal mine safety management, we elaborate the main application of data mining methods in coal mine safety management from ten aspects. The common problems, related big data algorithms and application purposes of these ten aspects are shown in Table 2.

(1) Unsafe behavior management
Unsafe behavior management is mainly aimed at the risk sources of employees who are prone to accidents in coal mining enterprises [10]. In the process of safety management, miners will produce much data on unsafe behavior, including attendance, safety training, violation times, violation grades, etc. At the same time, safety management is also affected by the education level, psychology, physiology and other factors of miners [11]. Therefore, we can use the classification algorithm in data mining to determine the characteristics of miners who are prone to unsafe behaviors.

(2) Hidden danger management
Hidden dangers are the direct fusion of coal mine accidents, and most of them are caused by the lack of comprehensive identification and management of hazard sources. Data on hidden danger management systems commonly used in coal mine enterprises include time, place, department and level of hidden danger. The whole process of coal mine hidden danger management is to identify potential hidden dangers, evaluate the level of a hidden danger, and formulate corresponding control measures to ensure rectification within a specified time.

(3) Accident management
The application of big data in accident management mainly includes accident prediction, classification and mechanism mining [12]. In coal mine accident prediction, we can use regression prediction in data mining to thoroughly mine time series data, such as the number of casualties, loss amount, and death rate per million tons in coal mine accidents, to identify future trends of coal mine accidents and provide a basis for subsequent decision-making. In accident classification, we can apply the classification algorithm in data mining to categorize the severity of coal mine accidents [13].

(4) Outsourcing management
In China, outsourcing has become a common method for many coal mining enterprises to mine coal. However, the staff composition and management level of outsourced coal mining teams are uneven, thus resulting in frequent coal mine accidents in recent years. The classification algorithm in data mining is adopted to deeply mine data on outsourcing enterprise qualification, enterprise accident rate and outsourcing personnel structure to better understand the safety management level of outsourcing management.
enterprises and provide a decision-making means for selecting outsourcing units of coal enterprises.

(5) Safety supervision management

The coal mine production supervision information platform constructed by data mining can realize state coal mine safety supervision by the local government and local government supervision of the coal mine safety enterprise [14]. Through implementation of information-integrated supervision of safety production data of each coal mine enterprise link, a corresponding real-time dynamic supervision service function can be provided to the production supervision department, thereby providing various safety service functions for the enterprises accessing the platform and achieving the interaction between coal mine enterprises and the government supervision department.

(6) Safety input management

Increasing the safety investment can reduce the occurrence of coal mine accidents to a certain extent, but enterprises need to maximize profits while ensuring safety. This requires that the safety input management of enterprises studies the relationship between coal mine safety input and safety benefits. A certain proportion of safety investment can reduce casualties and increase the marginal production efficiency of enterprises. However, when the marginal safety management input is smaller than zero, the coal mine production efficiency will decline.

(7) Safety equipment management

There are many custom production equipment in coal mine enterprises, such as shearers, local ventilators, air ducts, water pumps, and roof hydraulic supports. These devices have a large amount of associated dynamic safety data information. With the development of the Internet of Things technology, it is possible to monitor coal mine safety production equipment in real time. At the same time, according to the data produced by safety production equipment, fault diagnosis and early warning of production equipment are conducted with classification, clustering and prediction algorithms in data mining.

(8) Safety environment management

Most of the coal mines in China have a complex underground working environment, which leads to numerous accidents. Underground mining activities are affected not only by damp, dark, space-constrained and noisy conditions and other operating environmental factors but also by the ground pressure, gas presence, water permeability, spontaneous coal combustion and other natural environmental factors. When there are risk signs, early warning measures can be implemented in advance. In addition, the data mining algorithm can also be used to evaluate and predict gas emissions and rock bursts so that the calculation results are more in line with the actual situation.

(9) Risk management

Risk management is an important part of coal mine safety management. The use of big data mining technology for building a coal mine risk management platform can integrate all risk elements of coal mines and realize comprehensive coal mine risk management. Then, the big data correlation algorithm determines the coupling relationship among factors to more accurately evaluate the coal mine risk.

(10) Safety emergency management

The application of big data in emergency management mainly includes big data technology and big data thinking. Big data applications can be introduced at every stage of emergency management preparation, response, rescue and recovery, and the application degree of big data at each stage will also be different due to the different response contents. The application of big data helps to improve the emergency management efficiency, thereby reducing costs and losses.

4. Discussion on the challenges of coal mine safety under the background of big data

With the popularization of databases, cloud storage technology, the Internet of Things, radio frequency identification (RFID) technology and video monitoring technology, the ability of enterprises to acquire data has substantially improved. These technologies are also widely used in coal mine safety activities. Coal mine enterprises can extract relevant coal mine safety management information from a variety of information systems, such as environmental monitoring sensors, personnel positioning systems, equipment fault diagnosis systems, and safety information management systems.

However, the application of big data technology in the coal industry is still at the stage of research
and experimentation. Some of the foremost and difficult issues include combining big data technology with the coal safety production business, developing a large-scale software system platform and establishing a coal safety production big data analysis method system. The analysis method and functional and technical frameworks of coal mine safety production big data still require further research and optimization.

5. Conclusion

This article examines the research paradigm of coal mine safety management against the background of big data from three aspects of change, application and challenge. The specific conclusions are as follows:

(1) The safety management concept against the background of big data focuses more on objectivity, timeliness, foresight and relevance. From these four perspectives, the safety management concept exhibits both a certain timing and overlap. In addition, the safety management concepts of different periods have their own advantages and disadvantages. The safety manager of an enterprise should choose the appropriate safety management concept according to the characteristics and safety development stage of the enterprise.

(2) The emergence and widespread application of big data thinking undoubtedly creates convenient conditions for the innovation and development of various industries in society, especially coal mine safety management research. Big data thinking is profoundly changing coal mine safety management thinking. This includes the transformation from causal thinking to related thinking, static thinking to dynamic thinking, reverse thinking to positive thinking, and empirical thinking to data thinking.

(3) The application of big data in coal mine safety management is becoming more widespread. With the advent of the big data era, an increasing number of coal mining companies have realized the importance of informatization and big data in coal mine safety management. Big data analysis not only enhances the work efficiency of coal mines in terms of production, scheduling, transportation, and sales but also improves the safety management level of coal mine enterprises.

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