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REBUILDING
AUTONOMY
FLUID & COMPONENT LIFE
RENEWABLE FUEL OPTIONS
PAYLOAD OPTIMIZATION

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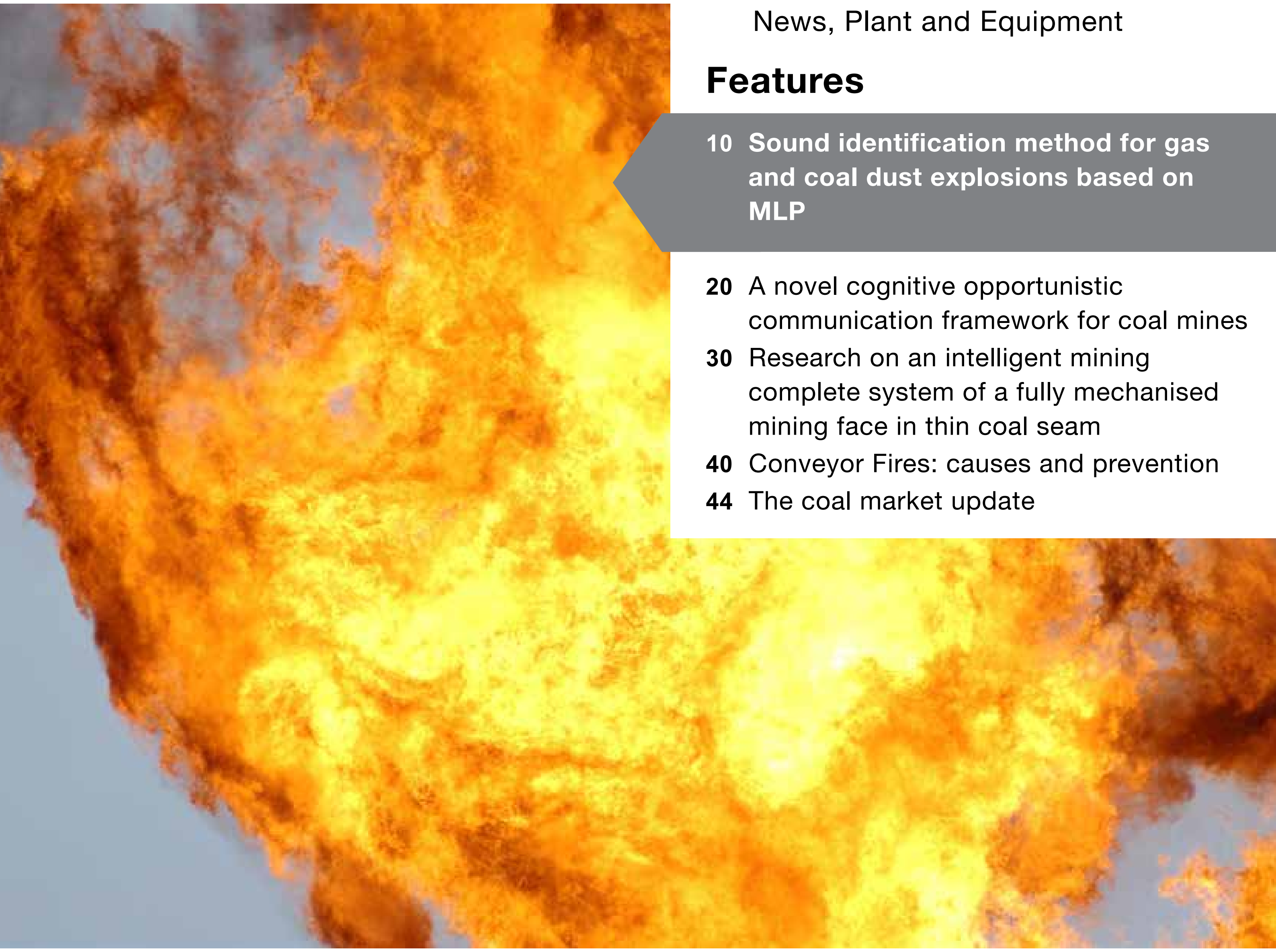

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Germany's coal exit on track – no forced closures needed

Recent reports that many of Germany's coal-fired power plants went offline this year, so many that the country's Federal Network Agency (BNetzA) had no need to impose a ban on these plants, partly because of an increase in renewable energy. The high number of market-driven coal power plant closures meant that the target for reduced capacity had already been exceeded this year. This is the first time it has not been necessary to impose a ban in order to achieve the target since Germany's legally binding coal phase–out began.

Coal capacity is being under-used because of the growing share of renewable energy in the mix. The share of coal in the electricity mix has dipped from 48 % nine years ago to 19 % in the first half of 2024.

In July, the country's economy ministry confirmed to CLEW that the government would not make any political efforts to bring forward the 2038 statutory deadline for exiting coal, despite a coalition government agreement to phase out the fossil fuel ideally by 2030. Instead, economy minister Robert Habeck said operators could voluntarily switch off the power plants deemed to be climate-damaging earlier, as rising CO_2 prices related to EU reforms would make coal-fired power plants increasingly non-viable.

BME, Hypex Bio continue to drive environment-friendly explosives

With 20-million tonnes of bulk nitrate-based explosives being used every year in the mining industry, contributing significantly to greenhouse-gas (GHG) emissions, explosives and detonation specialist BME is driving the development and market expansion of Hypex Bio's hydrogen peroxide emulsion (HPE) technology.

BME's parent company Omnia entered into a strategic partnership with Scandinavia-based Hypex Bio in 2023, securing Omnia's exclusive distribution rights of the technology in Canada and other major global mining markets.

Hypex Bio's HPE solution was the first commercially scaled nitrate-free emulsion explosive in the market, with more companies recognising its environmental and cost-saving benefits.

The HPE reduces nitrogen oxide air emissions by 90%, which addresses a critical environmental concern in the mining industry. The solution is also free from nitrates and ammonia, meaning it does not contribute to nitrate pollution in water sources.

Importantly, residual HPE decomposes into water and oxygen, leaving no environmental or health damage to surrounding communities.

BME MD Ralf Hennecke says the company's investment in Hypex Bio has been a good strategic fit and enhanced the company's competitive advantage in the market, given that customers are increasingly focused on sustainable, environment-friendly solutions in their operations.

The technology has been adopted at various underground mines and construction sites in Norway, Sweden and Denmark, with BME driving increased adoption of the technology in Canada as a starting point of its collaboration with Hypex Bio.

Hennecke emphasises that the solution is operationally non-disruptive and does not require extensive changes to blasting procedures.

Hypex Bio CEO Thomas Gustavsson says Africa is a key mining market that the companies will focus on in due course, with stakeholders starting to understand how HPE technology has the potential to increase safety and reduce environmental impact in the mining industry.

He adds that nitrate-based explosives often have supply chain vulnerabilities, whereas HPE does not.

The product ultimately reduces the need for water treatment plants and nitrate mitigation infrastructure, as well as costs in terms of mine ventilation when elimination of toxic gases is necessary. It allows for savings in emissions costs and for more favourable permitting requirements as it eliminates pollution from the explosives component of a mining application.

Coal research organisation Coaltech CEO Avhurengwi Nengovhela says decarbonisation is a complex endeavour in the mining industry, but companies are increasingly implementing projects for energy efficiency and emission reduction as an imperative.

BME GM Nishen Hariparsad says HPE offers value to customers in the form of confidence in blasting, particularly when it is coupled with BME's blasting initiation system, which targets safety, accuracy, environmental and operational efficiency.

Gustavsson concludes that by switching to more sustainable explosives such as HPE, mining companies can immediately reduce some of its biggest problems on mine sites, particularly as the world demands more minerals for energy transitions, while creating a new discipline in the explosives technology space that can take companies into the future.

Stanmore bolsters Isaac South's future

Stanmore Resources has entered into a binding agreement with Anglo American and Exxaro, the participants of the Moranbah South joint venture (MBS JV), granting Stanmore the rights to explore, study, and apply for a future mining lease over a designated area on the MBS JV tenements.

This area, immediately adjacent to Stanmore's Isaac South project, is expected to significantly enhance the economics of Isaac South by adding low-strip-ratio coal, thereby extending the life of operations beyond the currently mined Isaac Downs pits.

"This transaction paves the way for the development of our Isaac South project in a more competitive and lower-average-strip-ratio basis, as a natural capital efficient brownfield extension of our current Isaac Downs mine, prolonging the overall mine life at our Isaac Plains Complex," Stanmore chief executive officer Marcelo Matos said.

The addition of the designated area is projected to contribute approximately 50% of the total mineable resource of the enlarged Isaac South project.

The strip ratio is expected to start at just 4-5:1 run-of-mine, meaning the mine's development will have a lower capital cost and time to first coal will be faster.

The designated area is also strategically located near Stanmore's existing coal handling preparation plants, dragline, and associated infrastructure, further reducing development costs and timeframes.

The agreement entails an upfront payment of $US15 million, followed by a deferred consideration of $US20 million upon the first coal being mined or approximately 10 years after the grant of a mining lease. Additionally, a capped royalty of up to $US40 million is linked to certain coal price thresholds.

Stanmore plans to fast-track the project, with plans to submit all required documentation in 2025.

"We will now work closely and swiftly with State and Federal Government departments and regulators to progress the environmental impact studies and all associated work and secure all required regulatory approvals to submit an investment case for internal approval to start construction of the new pit and associated infrastructure," Matos said.

The company aims to maintain operational continuity at its Isaac Plains Complex, potentially adding another 15 years of mining at the current rate of four million tonnes per annum.

UK First G7 Nation To End Coal-Fired Power Generation

Britain's reliance on coal for electricity is set to end, over 140 years after it opened the world's first coal-fired power station in London in 1882

The UK is set to become the first G7 country to stop using coal to generate electricity, with the gates due to close on the country's last coal-powered plant at the end of the month, the Financial Times reported.

It's being seen as a key marker in the UK government's efforts to decarbonise its electricity supplies by 2030, while also meeting growing electricity demand, the story continued, and puts the UK ahead of Germany which plans to switch off its coal power supply by 2038, Canada by 2030 and mainland Italy from the end of 2025.

Coal supplied 80% of the UK's electricity in 1990 but only 1% last year, when 34.7% came from gas, 32.8% from wind and solar, 11.6% from bioenergy, and 13.8% from nuclear, the report went on.

The closure of the Nottinghamshire power station comes with the UK set to become far more power-hungry as households and businesses switch to electric cars and heat pumps, which is expected to see demand more than double by 2050.

Indonesian electricity company PLN announced plans to replace 800 coal-fired power plants (PLTU) with gas-fired power plants (PLTG) in order to achieve net zero emissions by 2060.

"We have a roadmap to achieve zero emissions by 2060 by replacing 800 coal-fired power plants with gas-fired power plants, and we have a biomass program [to achieve the goal]," said Wiluyo Kusdwiharto, PLN's Director of Project Management and New and Renewable Energy, in the Plenary Session of the Indonesia International Sustainability Forum (ISF) 2024 themed Future of Energy Transition in Emerging Economies in Jakarta.

PLN has already taken steps towards decarbonization by canceling the construction of the 14.5-gigawatts coal-fired power plant, which had been included in the 2019-2028 Electricity Supply Business Plan (RUPTL) and the 1.2-gigawatts coal-fired power plant through Power Purchase Agreements (PPAs). Additionally, the company has replaced the 1.1-gigawatts coal-fired power plant with renewable energy sources.

Wiluyo also explained that the PLN has replaced diesel power plants (PLTD) with cleaner alternatives as part of the De-dieselization Program by creating hybrid PLTDs powered by renewable energy sources."We have around 5,000 diesel power plants throughout Indonesia and we replace them by creating hybrid PLTDs with renewable energy, such as batteries. So the total cumulative emissions through this program are around 3.7 million tons of CO_2," said Wiluyo.

However, to achieve the zero carbon emission target, Wiluyo said Indonesia needs an investment of US$700 billion or Rp10,767 trillion to develop 423 gigawatts of new renewable energy. This investment amount is significantly higher than the 2025 Draft State Budget (RAPBN), which stands at Rp3.613.1 trillion.

South Africa's pilot carbon capture scheme officially inaugurated

The Council for Geoscience (CGS) announced recently that the country's first carbon capture, utilisation and storage (CCUS) research site had been officially inaugurated. This marked the conclusion of Phase 1 of South Africa's pilot CCUS project. However, the inauguration of the site, at Leandra in Mpumalanga province, actually took place just before this date.

This step followed the completion of a successful geological characterisation study of the site. This included the drilling of a 1 800 m stratigraphic borehole. This confirmed the site's suitability for the permanent and safe storage of CO_2.

"With support from the South African government and the World Bank, [the] CGS has made significant progress, including the completion of a comprehensive geological characterisation and feasibility study for the pilot injection plant," reported CGS CEO Moses Mabuza. "These findings reveal the site's capacity to store up to 34 gigatonnes of CO_2, paving the way for Phase 2, which will focus on design, construction and the injection phase."

Investigating CCUS is important to South Africa because the country is one of the worst CO_2 emitters in the world. This is a consequence of its heavy reliance on fossil fuels, particularly coal, to produce most of its energy.

"South Africa is responsible for approximately 500-million tonnes of CO_2 emissions annually, largely from coal combustion," highlighted Mineral and Petroleum Resources Minister Gwede Mantashe, in his address at the inauguration ceremony. "This initiative is a critical step towards reducing our carbon footprint. We urge all industry stakeholders to collaborate with us, providing the necessary financial and technical support to ensure the success of CCUS technology in South Africa."

As part of the inauguration event, the CGS signed a memorandum of understanding with the Mpumalanga provincial Department of Economic Development, Environment and Tourism. This provides the framework for the joint development of CCUS and related programmes.

"We have seen exceptional backing from local authorities, the Mpumalanga provincial government, and the Govan Mbeki local municipality, our host for this project," affirmed Mabuza. "Through our Public Advocacy Programme, we have fostered a deeper understanding among South Africans of the role CCUS technology can play in reducing emissions. The [CGS] is committed to driving this initiative forward and calls for the continued support of all stakeholders to achieve our shared climate mitigation objectives."

South Africa has been investigating the possibility of CCUS since 2004. The initial studies were carried out by the Council for Scientific and Industrial Research. The CGS has headed the pilot CCUS project since 2021.

Nippon Steel and JFE Steel buy into Australian coal mine

The Australasian Centre for Corporate Responsibility (ACCR) has commented on the recent announcement that Nippon Steel Corp. (NSC) and JFE Steel (JFE) have collectively bought 30% of Whitehaven Coal's Blackwater metallurgical coal mine in Queensland, Australia.

Breakdown:

- NSC will pay nearly US$720 million for a 20% stake in Blackwater.
- JFE is purchasing a 10% stake for US$360 million.

Whitehaven Coal is seeking to extend the life of the Blackwater mine by an additional 60 years, pushing the mine's life out to 2085, as part of its Blackwater North Extension Project.

In June, shareholders in NSC showed significant support for three climate-related shareholder proposals at the company's annual general meeting, which urged the world's fourth largest steelmaker to improve its decarbonisation strategy.

Commenting on the announcement, Fiona Deutsch, Lead Analyst at the Australasian Centre for Corporate Responsibility, said:

"Investors will be rightly questioning Nippon Steel's previous commitments to being a globally competitive leader in the green steel market with this stake.

"The recent strong support for three climate-related shareholder proposals at Nippon Steel's AGM suggests investors see a delay in decarbonisation as a risk to corporate value, and this investment will raise questions about the company's commitment to decarbonisation and meeting investor expectations.

"The transition risks associated with metallurgical coal are increasingly evident. As steelmaking processes evolve to reduce reliance on coal, the risk profile for metallurgical coal is expected to rise.

"A recent global survey of 500 investors across 34 countries showed that 80% believe metallurgical coal's risk profile will increase in the next decade.

"Instead of doubling down on the highest-emitting part of the steel supply chain, Nippon Steel and JFE should be leading the way in the transition to greener technologies. This is what investors expect.

"Nippon should be pivoting towards technologies with genuine green potential, including direct reduced iron (DRI) and electric arc furnaces (EAFs), and positioning itself as a leader in a decarbonising industry, securing both economic opportunities and climate benefits."

A blueprint for phasing out coal power stations in Asia

Countries in the Asia-Pacific region account for 76% of the world's thermal coal power generation, and many of these plants will need to retire early to meet global emissions targets.

But according to a new analysis, it's possible to phase these coal plants out and transition to renewable energy while investors still make money.

The study, done by Australian, Singaporean and Chinese researchers, was published in *Energy Policy*.

"There is a drive and interest from a number of different investors like the Asian Development Bank, but also private sector investors, to finance the early retirement coal fired power plants," lead author Professor Christoph Nedopil Wang, director of Griffith University's Asia Institute, stated,Nedopil and colleagues looked specifically at 6 Chinese-sponsored coal-fired power plants in Vietnam and Pakistan.

"With investors wanting to invest in, and ideally also providing lower cost financing for, green projects, refinancing of these coal fired power plants becomes possible at a lower cost," says Nedopil.

The researchers modelled the future performance of these stations under a variety of financing and geoeconomic scenarios.

"That brought us to the conclusion that, depending on the age of the coal-fired power plant, we can retire these plants earlier than currently envisaged, while reducing the financing cost and therefore increasing enterprise value," says Nedopil.

The plants could be retired between 3 and 13 years earlier than planned, while still preserving or increasing profits for investors.

Younger plants were the most promising cases.

"These coal-fired power plants have a lot of debt on their balance sheet – at the beginning, 75% debt. On this debt, the owners of the coal fired power plant, of course, have to pay interest rates. And if the interest of the debt portion is very, very high, most of the free cash flows will go to service the debt, and particularly the interest rate," says Nedopil.

"The young coal-fired power plants have this interesting window of opportunity for providing cheaper refinancing and therefore lowering interest rates."

While the findings relate to 6 specific plants, Nedopil says they'd apply in plenty of other countries.

"It's true for many different countries, particularly the ones that have young power plants. So it's not as true for Australian coal-fired power plants, for example, that are typically older and where the debt portion on the balance sheet is much lower.

"Refinancing would still be possible and interesting for older coal-fired power plants, but you'd have to use a slightly different mechanism to retire them early."

Nedopil says that Chinese stakeholders have taken interest in the team's coal phase-out research.

"China is the largest sponsor of coal fired power plants in Asia – not just in China, but also in non-Chinese Asian countries," he says.

But in 2021, President Xi Jinping announced that China would no longer be financing new overseas coal-fired power stations, and the country has rapidly increased its interest in renewables.

"I think there's a momentum that even 5 years ago we didn't think would have been possible," says Nedopil.

"Now, putting that all into practice, and seeing real examples around this, I think will be very interesting. We're still in the pilot phase. We have one or two early retirements of coal-fired power plants, for example, in the Philippines.

"But the scaling of this will be very tricky."

Nedopil adds that replacing coal with renewables in Asian countries will not be a simple task.

"From a technical perspective, there's growing electricity demand. And you can't just put a wind farm or solar farm exactly where the coal-fired power plant is, because the conditions are not right."

Then there's employment: coal is a big employer in the region.

"Reducing the dependency on these jobs must also carefully be considered," says Nedopil.

Fortunately, he says renewables are already a bigger employer across Asia than fossil fuels.

"This is quite a substantial developments over the last 5 years as well, that the green energy sector has already surpassed the brown energy sector in terms of employment."

A power plant in Mao Khe City, Vietnam.

Why Coal is Still a Cornerstone of the Global Energy Mix

Despite many nations transitioning away from fossil fuels, in 2023, world coal consumption reached a staggering **164 exajoules (EJ)** of energy, a record high for any year.

For this graphic, Visual Capitalist's Alan Kennedy has partnered with Range ETFs to explore the role coal plays in the global energy mix and determine which regions still consume large quantities of coal.

The Role of Coal in Global Energy

Coal is a significant player in the global energy mix, contributing 26% of the world's energy in 2023, more than all non-fossil fuel sources combined. The only energy source that contributed more to the global energy mix was oil.

Coal consumption has decreased in many regions. For example, both North America and Europe reduced their energy consumption from coal by 16% in 2023. However, a heavy reliance on coal in the Asia Pacific region has led to global coal consumption remaining essentially the same over the past 10 years.

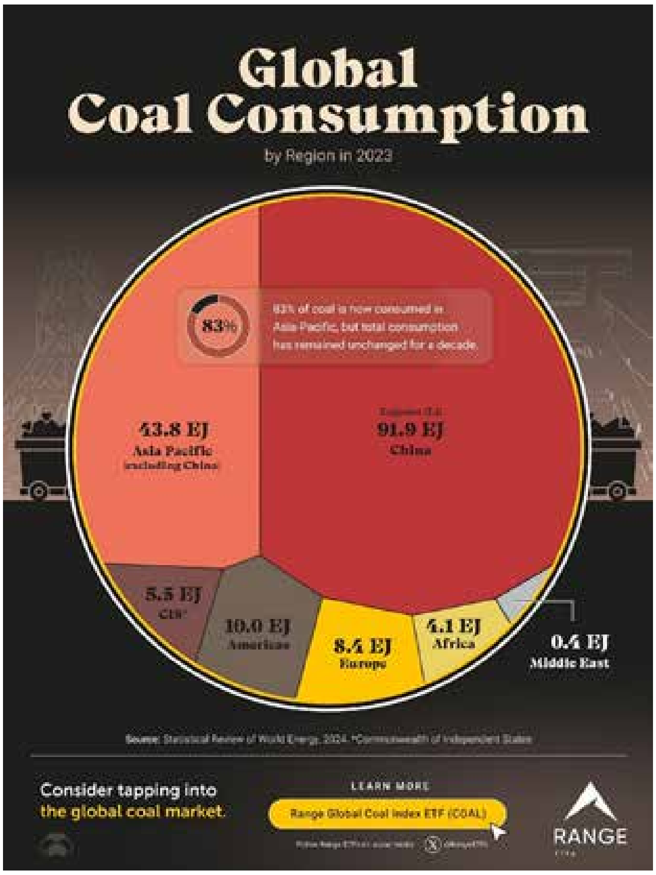
In 2023, China increased its coal consumption from 88 EJ to nearly 92 EJ – totalling 56% of global coal consumption. This contributed significantly to Asia Pacific leading the world with a staggering 83% of global coal consumption.

The Importance of Coal

Easy access to existing infrastructure and reasonable prices have not only sustained global coal consumption over the last 10 years, but also paved the way for potential growth. Many developing nations are now expanding their coal consumption, presenting potential opportunities in the coal market.

For example, as per the Statistical Review of World Energy 2024, between 2022 and 2023, Bangladesh and Colombia saw double-digit percentage increases in year-over-year coal consumption: 41% and 53%, respectively.

Coal continues to play a critical role in the global energy mix, especially in the developing world, where its affordability makes it the current energy source of choice.



Source: Statistical Review of World Energy, 2024. *Commonwealth of Independent States

U.S. Crude Oil Exports To Peak In 2024

Here's how that consumption breaks down by region:

Region	Conumption (EJ)
China	91.9
Asia Pacific (excluding China)	43.8
Americas	10.0
Europe	8.4
CIS*	5.5
Africa	4.1
Middle East	0.4
Total	**164.0**

Percentage may not sum to 100 due to rounding.
** Commonweath of Independent States*

Arch merges with Consol to create a coal-export powerhouse

US coal producer Arch Resources Inc. agreed to merge with rival Consol Energy in a $2.3-billion deal aimed at creating a North American mining heavyweight to deliver the fuel around the world.

The companies announced the transaction in a statement recently. Under the terms of the merger agreement, Arch stockholders will receive a fixed exchange ratio of 1.326 shares of Consol stock for each share of Arch common stock. Consol shareholders will own about 55% of the combined company, to be called Core Natural Resources.

The new company will own 11 mines producing thermal coal for power plants and metallurgical coal for making steel. While the dirtiest fossil fuel is a major driver of climate change, it's also among the commodities most crucial to the global economy. Demand for steel, and the materials used to produce it, is growing over the long term, while consumption of coal for electricity generation remains strong even as nations seek to shift to cleaner energy.

"The markets are out there," Deck Slone, Arch's senior vice president of strategy, said "You've got to get out there into the seaborne markets."

The transaction is expected to close by the end of the first quarter, pending regulatory approvals. Core Natural Resources will have ownership interests in two export terminals on the US East Coast, which are key to the company's export strategy. The company, to be based in Pennsylvania, will be able to export as much as 25-million tons a year, the most of any North American coal producer.

Both companies are dependent on customers outside of North America, and that shipping capacity will give the combined venture a strategic advantage, said Andrew Blumenfeld, director of data analytics at McCloskey by Opis. "Exports are what make this work," he said in an interview.

And this transaction may not be the last, said Blumenfeld. Once the Core Natural Resources merger is complete, he expects to see the combined company pursue additional deals, most likely in the metallurgical coal market. "I think this might be just step one," he said.

Executives stressed on the call that the two companies have little operational overlap, which should help the tie-up win regulatory approval. Arch's planned move to merge its operations in the Powder River Basin with those of rival Peabody Energy was rejected by a federal judge in 2020.

Earlier this year, Consol faced a significant threat to its operations after a catastrophic bridge collapse choked off Baltimore harbor and curtailed shipping to the company's export terminal a few miles away. Consol has focused on boosting overseas shipments in recent years amid shrinking domestic demand for the dirtiest fossil fuel. Baltimore's port has since fully reopened.

Moelis & Company LLC advised Consol, while Perella Weinberg Partners advised Arch.

"This transaction demonstrates our confidence in the future of coal," Jimmy Brock, Consol's CEO, said recently.

Sound identification method for gas and coal dust explosions based on MLP

To solve the problems of backward gas and coal dust explosion alarm technology and single monitoring means in coal mines, and to improve the accuracy of gas and coal dust explosion identification in coal mines, a sound identification method for gas and coal dust explosions based on MLP in coal mines is proposed, and the distributions of the mean value of the short-time energy, zero crossing rate, spectral centroid, spectral spread, roll-off, 16-dimensional time-frequency features, MFCC, GFCC, short-time Fourier coefficients of gas explosion sound, coal dust sound, and other underground sounds were analysed. In order to select the most suitable feature vector to characterise the sound signal, the best feature extraction model of the Relief algorithm was established, and the cross-entropy distribution of the MLP model trained with the different numbers of feature values was analyzed. In order to further optimise the feature value selection, the recognition results of the recognition models trained with the different numbers of sound feature values were compared, and the first 35-dimensional feature values were finally determined as the feature vector to characterise the sound signal. The feature vectors are input into the MLP to establish the sound recognition model of coal mine gas and coal dust explosion. An analysis of the feature extraction, optimal feature extraction, model training, and time consumption for model recognition during the model establishment process shows that the proposed algorithm has high computational efficiency and meets the requirement of the real-time coal mine safety monitoring and alarm system. From the results of recognition experiments, the sound recognition algorithm can distinguish each kind of sound involved in the experiments more accurately. The average recognition rate, recall rate, and accuracy rate of the model can reach 95%, 95%, and 95.8%, respectively, which is obviously better than the comparison algorithm and can meet the requirements of coal mine gas and coal dust explosion sensing and alarming.

INTRODUCTION

Gas explosions, coal dust explosions, and gas and coal dust explosions (hereafter referred to as gas and coal dust explosions) are serious accidents that occur in coal mines[1-4], which will cause casualties and economic losses once they occur. Therefore, a large number of researchers have conducted a lot of research on them. The existing measures of monitoring are mainly realised by gas and temperature sensors, which are outdated monitoring means and have problems, such as slow reporting, a false alarm rate, and a high leakage rate. Therefore, it is of great theoretical significance and practical value to study the intelligent identification and alarms of coal mine gas and coal dust explosions.

Sound has the characteristics of a long propagation distance and small influence by bending and branching of the tunnel[3-7]; therefore, sound recognition has achieved better results in explosion identification in coal mines. The authors of[4] analysed the characteristic differences between the sound of gas and coal dust explosions and other sounds in coal mines and proposed to realise the recognition of the sound of gas and coal dust explosions in coal mines by the method of sound recognition. The authors of[5] compared the decomposition results of coal mine underground sound through different EMD class signal decomposition methods and determined the use of the CEEMD decomposition method, extracted the sample entropy of the decomposed modal components used to characterise the sound signals, and input it into SVM to construct the sound recognition model. The authors of[6] propose the decomposition method of DTWCT to realise the decomposition and reconstruction of sound signals, extract the energy entropy ratio of its high-frequency components, which is used to characterise the sound signals, and input them into ELM to construct the sound recognition model. The authors of[7] propose the wavelet packet decomposition method to realise the decomposition of the sound signal, extract the energy ratio of its decomposition components, which is used to characterise the sound signal, and input it into the BP neural network to construct the sound recognition model.

With continuous deep learning research, sound recognition and classification have received great attention from researchers and practitioners, and sound recognition and classification have been widely applied first to environmental sound classification[8,9], noise signal classification[10], speech/music classification[11], music genre classification[12], speaker recognition[13], and indoor localisation[14]. In the literature[15,16], an automatic speech recognition system and powerful sound event classification were developed using deep neural networks, and the authors of[17] utilised deep recurrent neural networks for speech recognition and sound event classification.

To further improve the accuracy of coal mine gas and coal dust explosion recognition, it is necessary to conduct in-depth research in coal mine gas and coal dust explosion

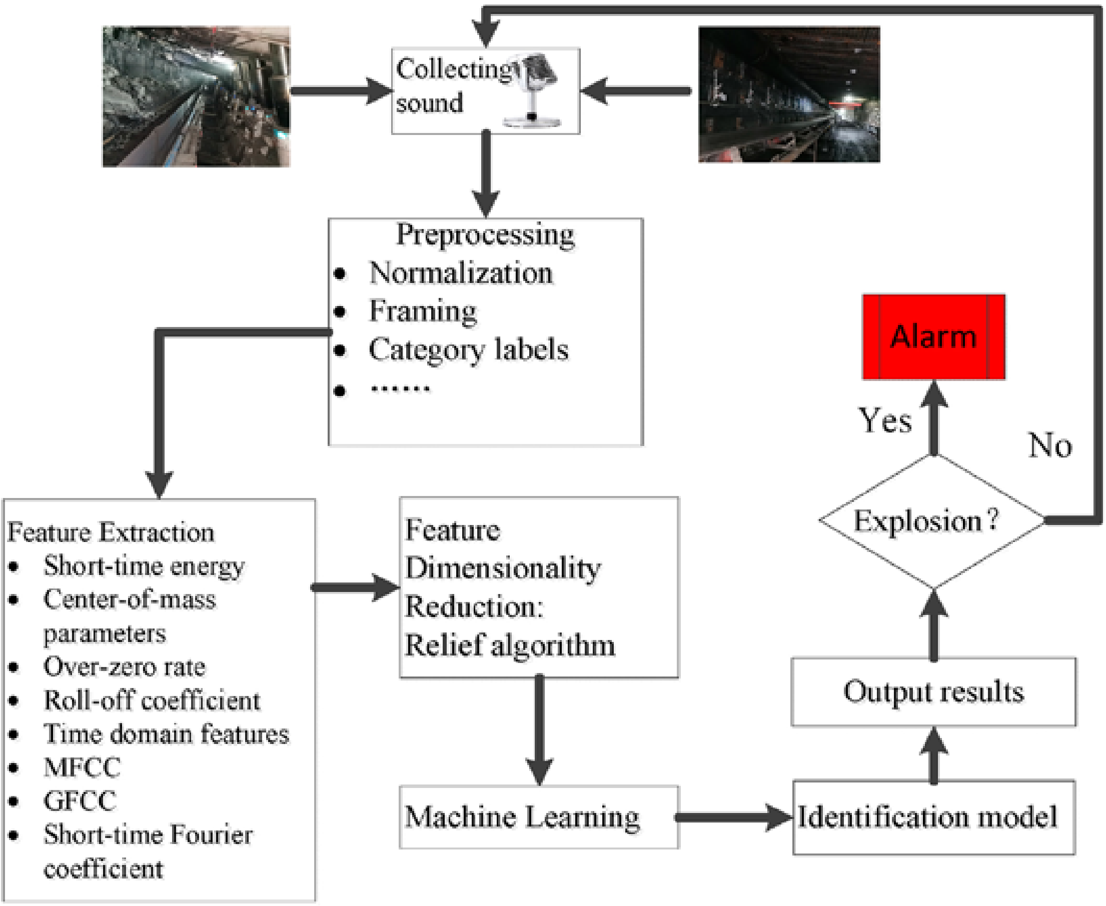


Figure 1: Working Principle Diagram.

sound recognition. Inspired by the research ideas of[15-17], we try to find a deep network suitable for actual coal mine production. Multi-layer perception (MLP) has the advantages of highly parallel processing, highly nonlinear global action, good fault tolerance, associative memory function, very strong adaptive and self-learning function, etc. Based on this, a sound identification method for gas and coal dust explosions based on MLP is proposed in this paper, which mainly includes the following aspects: (1) the real-time acquisition of sound signals in the monitoring area; (2) pre-processing of sound signals; (3) the extraction of the feature parameters of sound signals; (4) filtering less useful features by the Relief algorithm to achieve a reduction in the dimensionality of the extracted feature set; (5) establishing a machine learning recognition model; and (6) determining whether the sound is a gas and coal dust explosion by the model results. Working Principle Diagram is shown in **Figure 1**.

FEATURE EXTRACTION

Sound Material

In this paper, the experimental work of underground non-gas and coal dust explosion sound data collection was conducted in the Shuangma coal mine of the Shenhua Ningxia Coal Group. The sound of gas explosions and coal dust explosions is recorded by China Coal Industry Research Institute Chongqing Co. which located Chongqing, China.

The sound acquisition equipment is an HYV-E720 recorder with 16 GB memory, and all the audio files are mono with a 48 kHz sampling rate and saved in a .wav format. The data processing and experiments were performed on a Dell server using Matlab 2020a. The server is configured with an Intel i9-9980HK CPU@2.40 GHz, 32 GB RAM, and a 64-bit operating system.

Sound Characteristics

Compared to a single selection of a feature, different sound signal features can better describe certain aspects of the sound signal characteristics. To achieve a more comprehensive description of the sound signal, this paper will extract the signal statistical features, time-frequency domain features, sound features, etc. To realise the effective fusion of the extracted various sound features, this paper will use a Hamming window size of 1024. The frameshift is 50% of the window size, that is, 512, and the average value of all the extracted parameters will be used as the feature parameters of the sound signal. The distribution of each parameter is specified in **Table 1**.

The sound signal features selected in this paper have been proven to be effective in recognition classification work in different applications. Among them, the short-time energy, zero crossing rate, and 16-dimensional time-frequency features are all time-domain features of sound signals[18]; the spectral center of mass, spectral spread, and roll-off coefficient can effectively respond to the energy distribution features of sound signals[19]; the MFCC and GFCC are two common sound features widely used in the field of speech recognition[20-22], and short-time Fourier coefficients can effectively respond to the frequency domain features [23].

Table 1: Extracted features.

Feature Name	Dimension
Short-time energy	1
Center-of-mass parameter	2
Zero crossing rate	1
Roll-off coefficient	1
Time-domain feature	16
MFCC	12
GFCC	12
Short-time Fourier coefficient	25
Total	**70**

The short-time energy is the signal energy within a given window length, which reflects the strength of the sound signal at different moments. It is calculated as

Equation 1

$$E(i) = \frac{1}{N}\sum_{n=1}^{N}|x_i(n)|^2.$$

where $x_i(n)$ is the sound signal and N is the signal frame length.

The spectral center of mass and spectral spread are important parameters to describe the timbre properties. The spectral center of mass is the frequency in a certain frequency range by energy weighting, which reflects the brightness of the sound signal and is calculated as

Equation 2

$$C = \frac{\sum_{k=1}^{N} k \cdot A(k)}{\sum_{k=1}^{N} A(k)}.$$

where k represents the signal frequency and $A(k)$ is the spectral amplitude within a given time window.

The spectral spread is a measure of the spectral center-of-mass distribution and is a weighted average of the spectral center-of-mass bands, which is calculated as

Equation 3

$$S = \frac{\sum_{k=1}^{N} |k - C| \cdot A(k)}{\sum_{k=1}^{N} A(k)}.$$

where C is the center frequency band.

The zero crossing rate is the number of times the signal value passes through zero in a specified time, which reflects the number of times the signal passes through zero and reflects the frequency characteristics, and it is calculated as

Equation 4

$$Zn = \sum_{m=-\infty}^{\infty} |\mathrm{sgn}[x(m)] - \mathrm{sgn}[x(m-1)]|w(m).$$

where sgn() is the sign function.

Equation 5

$$\mathrm{sgn}[x(n)] = \begin{cases} 1 & x(n) \geq 0 \\ -1 & x(n) < 0 \end{cases}.$$

w(*m*) is calculated as

Equation 6

$$w(m) = \begin{cases} \frac{1}{2N} & 0 \leq n \leq N-1 \\ 0 & \text{else} \end{cases}$$

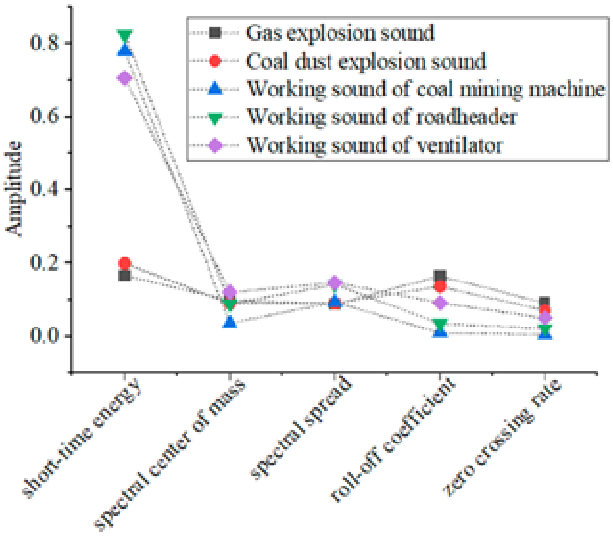


Figure 2: The mean value distribution of characteristics.

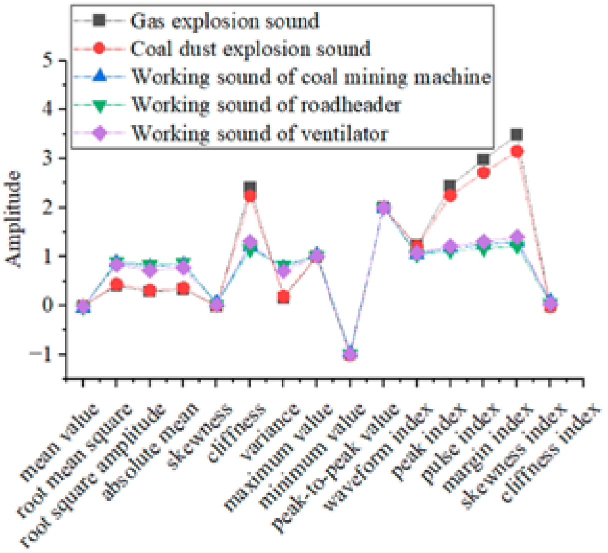


Figure 3: The mean value distribution of time-domain features.

The roll-off coefficient is a measure of spectral skewness, which is the percentage of the signal energy in the set frequency and reflects the signal.

The spectrum roll-off is a measure of the spectral bias, which is the percentage of the signal energy below a set frequency, reflecting the distribution of the signal energy, which is calculated as

Equation 7

$$\sum_{i}^{R} s_i(t) = \mathrm{a} \cdot \sum_{i=0}^{I-1} s_i(t).$$

where $s_i(t)$ is the signal energy of the ith frame and a is the general value. *I* is the total number of signal frames. *R* is the length of the sound signal. The general range of a is [0.8, 0.9], and 0.9 is used in this paper.

Due to the limitation of space, this paper will take the gas explosion sound, coal dust explosion sound, coal mining machine working sound, roadheader working sound, and ventilator working sound as the research objects by extracting the average values of five parameters, such as the short-time energy, spectral mass center, spectral diffusion, roll-off coefficient, and zero crossing rate, and the specific distribution is shown in **Figure 2**.

It can be seen from **Figure 2** that the mean values of the short-time energy, spectral center of mass, spectral diffusion, roll-off coefficient, and zero crossing rate of gas explosion sound and coal dust explosion sound are similar in magnitude and similar in distribution; the mean values of the short-time energy of coal mining machine working sound, road- header working sound, and ventilator working sound are similar in magnitude, but the mean values of the remaining four characteristics are significantly different in magnitude, and the mean values of the short-time energy of the gas explosion sound and the coal dust explosion sound differed significantly from those of the other three sounds. The mean values of the roll-off coefficient and zero crossing rate differed considerably, and the mean values of the spectral center of mass and spectral spread did not differ much.

The time-domain features selected in this paper include the mean value, root mean square, root square amplitude, absolute mean, skewness, cliffness, variance, maximum value, minimum value, peak-to-peak value, waveform index, peak index, pulse index, margin index, skewness index, cliffness index, etc. There are a total of 16 parameters, which can describe the time-domain features of sound signals more comprehensively. The average values of the time-domain characteristics of gas explosion sound, coal dust explosion sound, coal mining machine working sound, roadheader working sound, and ventilator working sound are also extracted, and their specific distributions are shown in **Figure 3**.

As can be seen from **Figure 3**, the average values of the time-domain features of gas explosion sound and coal dust explosion sound are similar in size except for the small differences in the average values of three parameters, namely the pulse index, margin index, and skewness index. The average values of the 16 parameters of the time-domain features of the coal mining machine working sound, coal mining machine working sound, and ventilator working sound have small differences and are highly similar. The time-domain characteristics of the gas explosion sound and coal dust explosion sound differ significantly from those of the other three sounds.

In addition, in this paper, in order to characterise the sound signal in more detail, the frequency-domain features that are widely used in the field of sound recognition are also selected, including MFCC, GFCC, and short-time Fourier coefficients, and the three frequency-domain features have been widely used in the fields of speech recognition, speech emotion recognition, and security monitoring.

MFCC mainly adopts the new metric *Mel* value, which is closer to the hearing mechanism of the human ear than the frequency, and the conversion relationship between the *Mel* value and the frequency value is shown in the following equation:

Equation 8

$$f_{Mel} = 2595 \cdot \log(1 + \frac{f}{700}).$$

where *f* is the frequency.

The process of *Mel* inverse spectrum coefficient extraction is: (1) adding a window and splitting frame: first, the sound signal is split into frames, which can increase the continuity between each frame of sound, and each frame of the signal after splitting the frame is multiplied by the window function for filtering; (2) the windowed signal is passed through the fast Fourier transform to obtain the energy distribution of the signal on the spectrum; (3) the discrete power spectrum is calculated. The log energy is obtained by filtering through a set of Meier filters; and (4) the log energy calculated in step (3) is discrete cosine transformed to obtain the MFCC coefficients.

The feature extraction of GFCC is based on a more comprehensive model of an equivalent rectangular bandwidth scale and a set of Gammatone filters, which simulates the process of the human auditory system for sound signals, and its coefficient extraction process is as follows: steps (1)-(2) are the same MFCC coefficient extraction process; (3) pass the energy spectrum through a set of Gammatone filters; (4) calculate the shorttime log energy; and (5) process the log energy by discrete cosine transform to obtain the GFCC coefficients.

The short-time Fourier coefficients realise the connection between the time and frequency domains of the signal, and the process is to multiply a time-limited window function h(t) before the Fourier transform of the signal and assume that the non-stationary signal is stationary in the short interval of the analysis window. The short-time Fourier transform of the signal x(τ) is defined as

Equation 9

$$STFT(t,f) = \int_{-\infty}^{\infty} x(\tau)h(\tau - t)e^{-j2\pi f\tau}d\tau.$$

where *STFT*(*t*,*f*) is the spectrum at time *t* and *h*(*τ* − *t*) is the analysis window. According to the previous theoretical analysis, the average values of the MFCC eigen-values, GFCC eigenvalues, and short-time Fourier coefficients of gas explosion sound, coal dust explosion sound, coal mining machine working sound, coal mining machine working sound, and ventilator working sound are also extracted, and their specific distributions are shown in **Figures 4-6**.

As can be seen from **Figure 4**, the mean values of the MFCC eigenvalues of gas explosion sound and coal dust explosion sound are similar in size and have a similar distribution. The mean values of the MFCC eigenvalues of the working sound of the coal mining machine, roadheader, and ventilator have a significant difference in size in the first 6 dimensions of the MFCC eigenvalues, and the remaining 6 dimensions do not differ greatly in size. The mean values of gas explosion sound, coal dust explosion and working sound of coal mining machine, roadheader, and ventilator have large differences in the 1st, 4th, 6th, 7th, 9th, and 12th dimensions, and the differences in the remaining 6 dimensions are not significant.

As can be seen from **Figure 5**, the mean values of GFCC eigenvalues of gas explosion sound and coal dust explosion sound are similar in size and have a similar distribution; the mean values of GFCC eigenvalues of working sound of coal mining machine and roadheader are similar in size in the first six dimensions of the mean GFCC eigenvalues, with little difference in size in the remaining six dimensions; the mean values of the GFCC eigenvalues of the working sound of the ventilator and roadheader in the last six dimensions are similar in value, and there is little difference in the value in the remaining six dimensions. The mean values of the GFCC eigenvalues of gas explosion sound, coal dust explosion sound, and working sound of the coal mining, roadheader, and ventilator have some similarities; there are small differences in the magnitudes of the values.

From **Figure 6**, it can be seen that the mean values of the short-time Fourier coefficients of gas explosion sound and coal dust explosion sound are similar in size, and the distribution is more similar.The mean values of the short-time Fourier coefficients in the 1st, 2nd, 4th, 5th, and 6th dimensions of the working sound of the coal mining machine have a large difference in size. The mean values of the short-time Fourier coefficients in the 1st, 2nd, 4th, 5th, and 6th dimensions of the working sound of the roadheader have a large difference in size, and the mean values of the short-time Fourier coefficients in the first six dimensions of the working sound of the ventilator have a large difference in size. The remaining 19 dimensions of the short-time Fourier coefficient average values are similar, and the similarity is high.

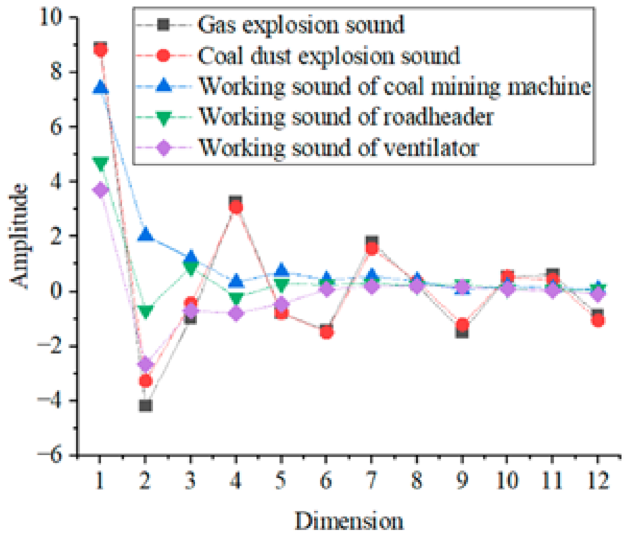


Figure 4: The mean value distribution of MFCC.

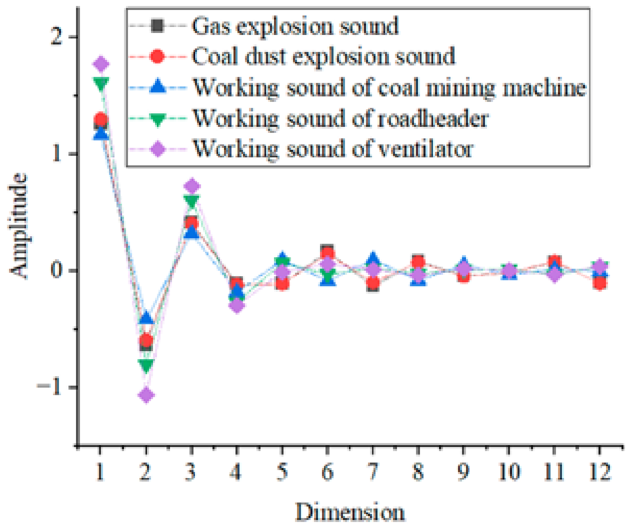


Figure 5: The mean value distribution of GFCC

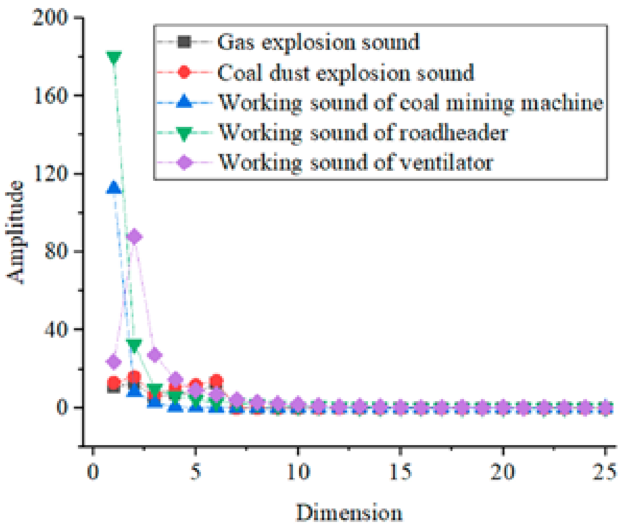


Figure 6: The mean value distribution of short-time Fourier coefficients.

Through the above analysis, it can be seen that most of the 70-dimensional feature parameters selected in this paper have large differences, and there are still a small number of feature parameters with too high similarity, which will greatly hinder the establishment of the recognition model and affect the accuracy and precision of the recognition model. Therefore, it is necessary to achieve the establishment of the optimal recognition model by selecting the best features as the characterisation sound.

Optimal Feature Extraction

In this paper, a total of 70 features of commonly used sound signals are selected. To select the features that are more compatible with the sound signals, this paper will realise the selection of features using the Relief algorithm, whose main idea is to assign weights to each feature and then sort them, and the weight of each feature is calculated based on the homogeneity of neighboring features. The specific process is as follows:

1. Loading the feature dataset into the code for pre-processing, removing the duplicate items, and recording the features of the sound signal, the category of the sound signal, and its parameters, respectively;

2. Calling the features of the sound signal, the category of the sound signal, and their parameters by the Relief algorithm, and the output of this function is an idx table containing the features sorted in descending order of importance and a table containing their weights;

3. The data are shuffled using the pseudo-random number generation function, randperm. Before each call to the function, the command rng (0) is invoked to ensure the same initialisation of the random process and obtain the same result in each execution of the program;

4. Based on the predetermined judging index, suitable parameters are selected as features to characterise the sound signal.

To objectively evaluate the best feature extraction method proposed in this paper, a fivefold cross-validation scheme is used, i.e., the training samples are divided into five parts, i.e., the data are equally divided into five equal parts, and one of them is taken for testing and the others for training each time. After training the recognition model and calculating the cross-entropy based on the prediction results of the model in the test and validation set entropy, we find the feature parameter corresponding to the smallest cross-entropy, which is the best point of the number of feature parameters; according to the distribution of the cross-entropy around the best point, we select the number of feature parameters with similar cross-entropy and input them into the training model together and select the best number of features by the recognition according to the distribution of the cross-entropy around the best point. The number of features with similar cross-entropy is selected and input to the training model, and the optimal number of features is selected through the recognition result to achieve the optimisation of the model.

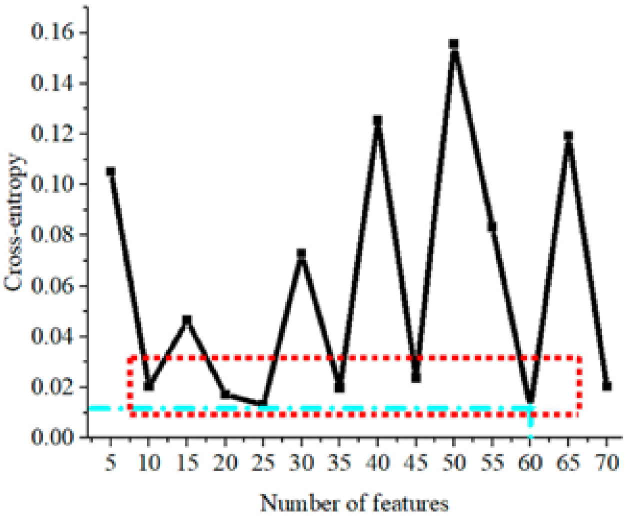


Figure 7: The distribution of cross-entropy.

RECOGNITION MODEL ESTABLISHMENT

Sound Data

The training samples include 5 groups of each sound, resulting in 80 groups in total; the test samples include 100 groups of each sound, resulting in 1600 groups in total.

Feature Parameter Determination Test

In this paper, the determination of the optimal number of features is achieved using MLP [24]; therefore, this paper needs to select the number of neurons, a training function, and a performance function of each hidden layer, and the specific parameters of the model function are specified as follows:

1. After experimental verification, the ideal number of neurons for the first hidden layer and the second hidden layer are 20 and 80, respectively.
2. Training function: The network training function selected in this paper is Trainrp, which means the backpropagation method. Therefore, the weight update of the network training is performed by minimising the cost function.
3. Performance function: This paper uses cross-entropy as the quality evaluation index of the network performance[25]. In the classification model, identification as a certain class belongs with a probability of 1, and for other classes, it belongs with a probability of 0. Each model estimates the probability that a record belongs to a certain class. The cross-entropy is the difference between two distributions. It is minimised in the same way as the likelihood function is maximised.

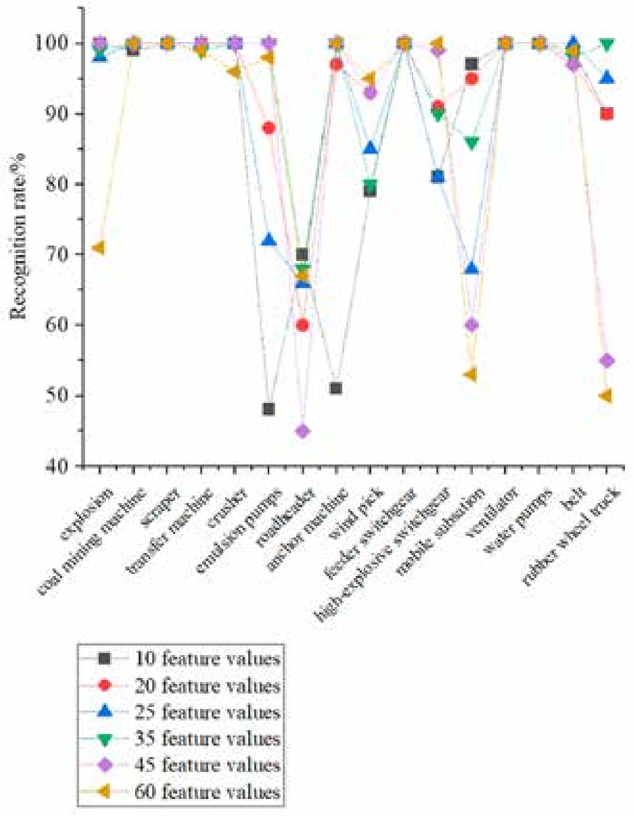


Figure 8: Recognition model recognition results.

In this paper, according to the steps in Section 2.3, to select the best feature parameters in the Relief algorithm output idx table to take the first 5, 10, 15, ..., 65, and 70 feature parameters into the MLP and calculate the cross-entropy distribution obtained for each group of feature parameters, the input model training is shown in **Figure 7**. As can be seen from **Figure 7**, the light blue marked point is the point with the smallest global crossentropy value, corresponding to the number of feature values of 60 when the value of cross-entropy is 0.01184; however, the value of cross-entropy corresponding to the feature parameters in the red box line is less different from that when the number of feature values is 60. Therefore, in this paper, the recognition results corresponding to the number of feature values in the red box will be discussed and verified to select the optimal number of feature values.

To select the best feature parameters for the model training, this paper also discusses the final recognition results of the recognition model after the corresponding feature parameters are input into the MLP to build the voice recognition model when the number of feature parameters is 10, 20, 25, 35, 45, and 60, and the specific results are shown in **Figure 8**. As can be seen from **Figure 8**, when the number of feature values is 60, the recognition result of the trained recognition model is the worst among several comparison models; therefore, the final recognition result of the recognition model is not directly related to the number of feature values. The recognition result of the sound recognition model proposed in this paper is better in gas and coal dust explosion sound, coal mining machine working sound, scraper working sound, and reloader working sound. The recognition results of the emulsion pump working sound, digging machine working sound, anchor machine working sound, wind pick working sound, mobile substation working sound, and rubber wheel car driving sound are poor; other sounds can be recognised by the recognition model after selecting suitable feature values.

After analyzing the cross-entropy distribution and the overall recognition effect of the sound recognition model, it can be seen that the best sound recognition model can be trained when the number of feature values is taken as the first 35 feature values and input to MLP.

MLP Model Building

MLP is a forward-structured artificial neural network that maps a set of input vectors to a set of output vectors, and the MLP can be viewed as a directed graph consisting of multiple node layers, each of which is fully connected to the next. In addition to the input nodes, each node is a neuron with a nonlinear activation function. A supervised learning approach using a BP (backpropagation algorithm) is used to train the MLP, which is a generalisation of the perceptron and overcomes the weakness that the perceptron cannot recognise linearly indistinguishable data.

In the training phase of MLP, the first 35-dimensional feature values determined in Section 2.1 are input into the MLP to initialise the weight matrix and bias coefficients. There is a total of p neurons in layer m−1 of the network, and then the output value of the jth neuron in the mth layer is

Equation 10

$$\alpha_j = g(\sum_{i=1}^{p} w_i^m \alpha_i^{m-1} + b_i^m).$$

where W_im is the weight of the ith neuron in the mth layer, α_i^{m-1} is the output value of the ith neuron in the (m−1)th layer, b_i^m is the bias vector of the jth neuron in the mth layer, and $g(\cdot)$ is the nonlinear activation function.

The error is calculated using the output value, and the sample is then used to update the weights using backpropagation until the output error is lower than the preset value. The output error is calculated as follows:

Equation 11

$$LOSS = \frac{1}{2}\sum_{p=1}^{M} (y_p - \hat{y}_p)^2 .$$

where y_p is the true label and $\hat{y}p$ is the predicted value.

Finally, the test sample set is fed into the completed training MLP model to obtain the final sound classification results.

RESULTS

To quantitatively evaluate the proposed sound recognition method, the recognition rate, accuracy rate, and recall rate are used as the evaluation criteria of the proposed method.

The accuracy rate refers to the probability that all the samples with positive predictions are positive samples, which is calculated using the following formula:

Equation 12

$$precision = \frac{TP}{TP + FP}.$$

where *TP* represents the number of positive predicted samples and the actual number of positive samples, and *FP* represents the number of positive predicted samples and the actual number of negative samples.

Recall refers to the probability of a positive sample being predicted out of an actual positive sample and is calculated as

Equation 13

$$recall = \frac{TP}{TP + FN}.$$

where *FN* is the number of predicted negative and actual positive samples.

Model Runtime

In practical engineering applications, the accurate and efficient identification of coal mine gas and coal dust explosions is crucial for coal mine safety production and safety rescue work. This experiment was performed on a DELL server with an Intel i9-9980HK CPU@2.40GHz, 32Gb memory, and a 64-bit operating system using MATLAB2020a. To avoid errors, the results of each test were averaged by performing 10 repetitions of the experiment, and the running time of each part of the proposed method in this paper is shown in **Table 2**. As can be seen from **Table 2**, the best feature extraction in this paper takes the most time, which is about 15.52 s. The feature extraction, MLP training, and recognition take 0.05 s, 0.83 s, and 0.62 s, respectively. Considering that the best feature extraction can be conducted again during non-working hours, it does not affect the normal working time. This method can complete the feature extraction, model training, and recognition process in less time on a less configured hardware platform, which has high computational efficiency and meets the requirement of the real-time safety monitoring and alarm system in underground coal mines.

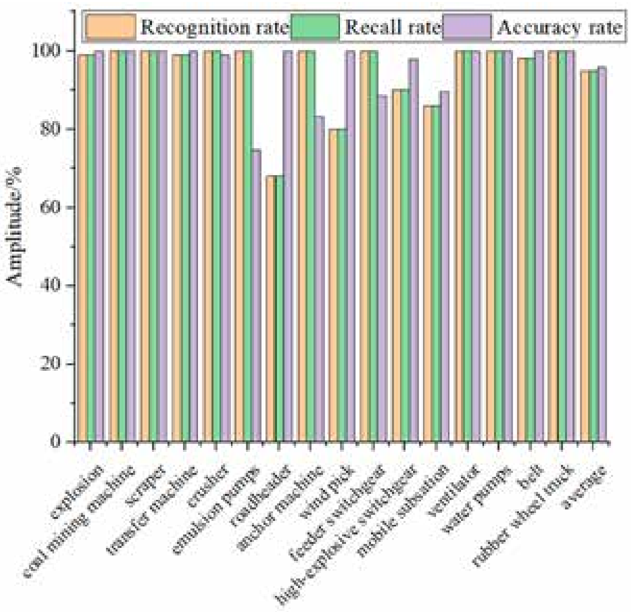


Figure 9: Identification results.

Table 2: Time consumption.

Model	Time Consumption/s
Feature extraction (single sample)	0.05
Optimal feature extraction (80 training samples)	15.52
MLP training (80 training samples)	0.83
MLP recognition (1600 training samples)	0.62

Table 3: Recognition results of classification models.

Model	Recognition Rate/%	Recall Rate/%	Accuracy Rate/%
Methods in this paper	95	95	95.8
Literature 5	85	83.3	71.4
Literature 6	93	100	81.1
Literature 7	95	75	100

Comparison of Results

To evaluate the proposed sound recognition method for coal mine gas and coal dust explosions, this group of experiments also took five groups of each sound (80 groups in total) to form the training sample set and 100 groups of each sound (1600 groups in total) to form the test sample set. The training sample set is trained by feature extraction, best feature value extraction, and the MLP model to obtain the recognition model, and the test sample set is input to the recognition model, and the final recognition results are shown in **Figure 9**.

As can be seen from **Figure 9**, the recognition rate and recall rate of the algorithm proposed in this paper are higher than 90% for all the sounds, except the sound of the working sound of the roadheader, wind pick working, and mobile substation working, and the accuracy rate of all the sounds, except the working sound of the emulsion pump, anchor machine, and mobile substation working, is higher than 90%. The average recognition rate of the algorithm proposed in this paper reaches 95%. The average recall rate is 95%, and the average accuracy rate is 95.8%.

To verify the advantages of the coal mine gas and coal dust explosion sound recognition method proposed in this paper, the recognition results of the algorithm in this paper are compared with the coal mine gas and coal dust explosion sound recognition results proposed in the literature[5-7], and the specific comparison results are shown in **Table 3**. As can be seen from **Table 3**, the algorithm proposed in this paper has a recognition rate of 95%, which is 10% and 2% higher than that in[5,6], respectively and is the same as that in[7]; the recall rate in[6] is up to 100%, which is 5% higher than that of the algorithm proposed in this paper and 16.7% and 25% higher than that in[5,7], respectively. The algorithm proposed in this paper has an accuracy rate of 95.8%, which is higher than that in[5,6], 24.4% and 14.7% higher than in[5] and 4.2% lower than in[7], respectively. Comprehensive analysis shows that the recognition effect of the algorithm proposed in this paper is significantly better than the compared methods, and the algorithm proposed in this paper can effectively distinguish each kind of voice involved in the experiment.

CONCLUSIONS

1. In this paper, a sound identification method for gas and coal dust explosions based on MLP was proposed. The distributions of the short-time energy, zero crossing rate, spectral center-of-mass parameters, spectral spread, roll-off coefficient, 16-dimensional time-frequency features, MFCC, GFCC, and the average of the short-time Fourier coefficients of 16 sound signals, including coal mine gas and coal dust explosion sounds collected in the field, are analyzed, which can effectively distinguish coal mine gas and coal dust explosion sounds from non-coal mine gas and coal dust explosion sounds.

2. The best feature extraction model is established, and the influence of different numbers of feature value parameters on the model training situation and recognition results is analyzed. With the cross-entropy and model recognition rate as the evaluation objects, the best feature parameters can be selected to avoid the influence of feature parameters with poor discrimination on the model training, and the compatibility and portability of this method can be effectively solved.

3. The experimental results show that the proposed algorithm can effectively distinguish each kind of sound signal participating in the experiment, and the average recognition rate reaches 95%. In addition, the method proposed in this paper can be used not only for the intelligent recognition of coal mine gas and coal dust explosions but also for monitoring abnormal sounds in underground coal mines; by modifying the training data set, it can also be used for monitoring abnormal sounds in other large public places, such as tunnels and subways.

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For further references and reading please use the link acknowledged. https://www.mdpi.com/1099-4300/25/8/1184

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A novel cognitive opportunistic communication framework for coal mines

The dynamic advancement and harsh environment of coal mines often result in intermittent or regional wireless connection between sending nodes and receiving nodes and then lead to the decrease of transmission success ratio and even failure. To solve this problem, the environmental cognition and best-effort transmission are both demanded. Here we proposed a novel communication framework for coal mines based on a cognitive opportunistic concept to address the wireless network communication problems in coal mines, which consists of the node mobility model in coal mines, cooperative cognition of the time-varying communication environment, and the opportunistic routing of intermittent or regional connection scenarios. To realise this framework, real time neighbour discovering mechanisms and mobility perceiving strategies, called environment cognition, must be deeply investigated to predict the trends of node movement. The obtained results of environment cognition are then used to analyse current channel characteristics to determine and set optimum communication system parameters and reduce the probability of intermittent or regional connection. To address those unavoidable situations of the intermittent or regional connection, the opportunistic routing mechanism is brought forward to provide relatively stable data transmission. Finally, as an example of cognitive opportunistic mine communication of this framework, personnel evacuation under an emergency is discussed.

Coal production and consumption has been playing an important role in the energy industry of China. It is crucial for the safe and efficient production to monitor environmental parameters, equipment status, personnel information, production situations, and security status and send these parameters to the ground monitoring center in real time via the ubiquitous mine internet of things (MIoT). A mine roadway, comprised of rough coal, rock, and bolt-beam mesh, has extensive branches and bending with narrow and long space. At the same time, a mine roadway is full of metal supports, large production equipment, transportation vehicles, and steel rails, resulting in strong multipath effects, serious fading, and significant interferences of radio wave propagation.

Particularly, all equipment in a coalface must keep advancing throughout the mining process, which causes dynamic changes of the communication space.

1. Due to the mine roadway characteristics, wireless communication systems used in mines face unique difficulties compared to those used on the surface, such as the following:
2. Communication nodes may be damaged by coal, rocks, or humans, resulting in intermittent or regional network connections.
3. The time-varying physical communication space forces wireless channels into a time-varying state, resulting in intermittent network connections; and
4. The great amount of dust produced during the coal cutting process and the presence of large, moving metal equipment result in poor adaptation to wireless communication systems, whose main effect on communication systems is also regional or intermittent node connection.

To address the wireless communication problem of intermittent or regional connection in mine roadways, two critical difficulties must be resolved: adaptation ability of communication systems to the changing environmental parameters and the relatively stable transmission ability under an inevitable unstable condition of intermittent or regional connection. This article proposes a novel cognitive opportunistic communication framework for coal mines to enhance the ability of the MIoT to adapt to the mine roadway environment and ensure that monitoring signal will not be interrupted by the harsh time-varying transmission environment, supporting, and guaranteeing the construction of digital and intelligent mines.

Compared to existing communication frameworks for ground applications, our framework includes components specific to coal mines to address the special communication difficulties met by the roadway. Compared to existing communication frameworks for coal mines, this framework includes models specific to special roadway sites and emergency situations based on opportunistic and cognitive technologies to deal with communication problems introduced by regional or intermittent connection.

Our major contributions are summarised as follows:

1. We reviewed the state of the art of the wireless communication technologies in coal mines and revealed their characteristics and key challenges. Besides, we also analysed the reasons why communications systems used in surface environments cannot be directly utilised in coal mines.
2. We proposed a cognitive opportunistic mine communication framework, which can adapt to the dynamic advancement and vulnerability of mining nodes and is thus of great significance to guarantee the successful communication
3. Some key technologies were deeply investigated, such as the node mobility model in coal mines, cooperative cognition of the time-varying communication environment, and the opportunistic routing of intermittent or regional connection scenarios
4. An application example of personnel evacuation under an emergency scenario was explored to demonstrate the effectiveness of the framework

The remainder of this paper is organised as follows.

Section 2 surveys some typical wireless communication systems and their challenges in mines and proposes a cognitive opportunistic mine communication framework.

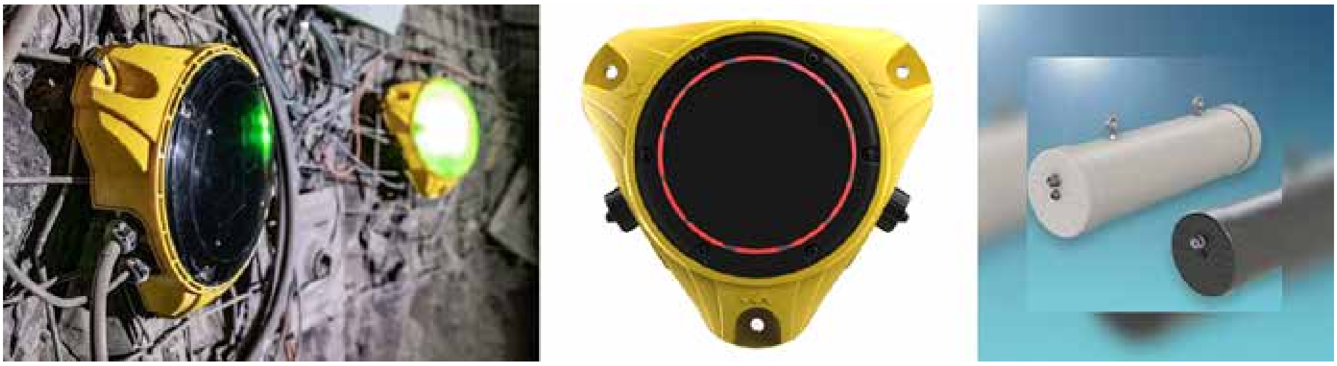
Section 3 details the three key technologies involved in the proposed framework, namely, the construction of the node mobility model, cooperative cognition of the time-varying communication in the mine roadway, and the opportunistic routing of intermittent or regional connection scenarios. As an exemplary application scenario.

Section 4 discusses the application of cognitive opportunistic mine communication for personnel evacuation in an emergency.

COGNITIVE OPPORTUNISTIC MINE COMMUNICATION FRAMEWORK

State of the Art of Wireless Communication in Mines.

Existing investigations into wireless mine communication have generally focused on the propagation characteristics of a wireless signal, network models, network protocols, and communication system development.



Examples of wireless nodes

Propagation Characteristics of a Wireless Signal

Typical research methods in this field are ray tracing, waveguide theory, and experimental testing. Ray tracing is a method to investigate the transmission characteristics of a wireless signal by tracing the path of rays[2], which is often inefficient because of the strong multipath characteristics present in most mines. The fourteen-waveguide method regards a mine roadway as a waveguide to study the transmission characteristics of a wireless signal[3]; however, the complex mine environment often produces significant differences between results obtained by a waveguide theoretical model and those obtained by practical testing. Experimental testing is a method often used to obtain such statistical characteristics as path loss and delay spread of roadways by conducting field investigations[4]; experimental conclusions are often closely related to the experiment locations and signal frequencies.

Network Models

Typical mine network models include chain models and mesh models. The chain model deploys wireless nodes linearly along a roadway corresponding to its linear characteristics[5], but it is more likely to form energy holes. In a mesh model, some nodes such as access points act as backbone nodes, interconnecting with each other to form a mesh network[6]; some access points which have accessibility to the wireless sensor networks are referred to as gateways. Thus, this type of network is essentially a mixed network composed of wireless and wired components which requires support from transmission cables[7].

Network Protocols

The purpose of protocol design is typically to expand network coverage, improve success ratio of message transmission, and reduce energy consumption or transmission delay. Network coverage is primarily implemented by studying different node deployment methods[8], which must consider the relationships among the coverage model, the roadway width limit, and node redundancy. Success ratio of transmission and network energy consumption are often the greatest challenges to successful wireless network communication[9]. Some nodes in a chain network model will not work any longer once their energy becomes depleted[10]. Finally, transmission delay is related to the type of data and the method of relay node selection[11].

System Development

Primary types of wireless communication systems in mines include ultra-low-frequency, through-the-earth communication, medium-frequency induction communication, leaky feeder communication, personal handy-phone, ZigBee, and Wi-Fi systems[12]. These systems are typically transplanted from ground systems without consideration of the special difficulties presented by the mining environment. Many systems are unable to adapt to the complex, changing communication environment of mines and may only prove to be effective in a part of a mine or roadway, but ineffective in the overall mining environment[13].

The reason wireless communication technologies on ground cannot be directly applied to mine roadways is that communication systems must be able to perceive the complex and changing environmental characteristics around them and tell these results to their communication partners in a timely manner, to increase the cooperative communication abilities.

Traditional wireless communication systems which utilise relatively fixed parameters such as communication frequency, modulation method, and bandwidth are often unable to adapt to the dynamic and various changes in a mining environment. Additionally, in a complex environment like the mine roadway which contains many devices as well as various geological structures and roadway interconnections, data transmission and reception between wireless communication nodes must follow a suitable routing protocol to be dynamically adaptive to the environment.

Take the coalface, the forefront of coal production, as an example. To enable the coal cutting, roof supporting, and coal transporting, all miners and mining equipment (such as the

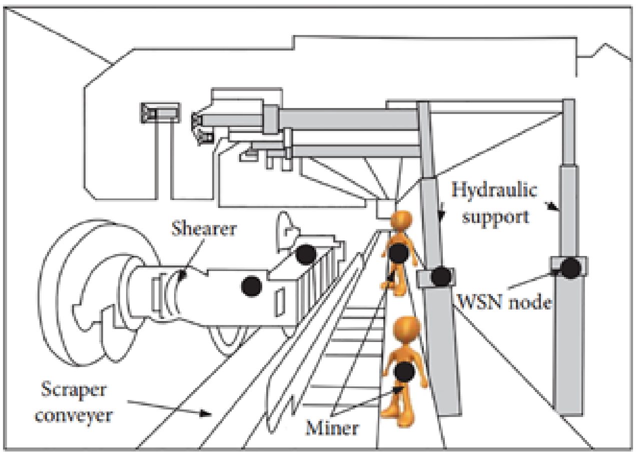


Figure 1: Coalface and its WSN deployment

shearer, hydraulic support operator, and scraper conveyor operator) must cooperate closely. The dynamic advancement of the equipment at the coalface forces the communication space into a time-varying state, making it impossible to lay additional wired communication cables in a timely manner. Under these conditions, wireless communication must be flexible to deploy and easy to extend as the mining face advances. For this purpose, wireless sensor network (WSN) nodes can be deployed on the hydraulic supports, shearer, and miners (**Figure 1**)[14]. Test nodes move along with the equipment and miners, leading to a linear (chock type support) or bilinear (chock-shield support) topology based on the linking conditions. Because of the extensive existence of the reliable wired/wireless networks in tailgates or headgates, the wireless sensor network at the coalface can easily transmit its messages to access points in gateways and then to other regions of the mine or ground information center. That is, these access points will be the sink nodes of the WSN in a coal mine.

Unfortunately, the information at the coalface cannot always be transmitted to the sink node due to the intermittent or regional connections, which is a frequent situation encountered in mine roadways. For example, coal production may make some network nodes occasionally damaged and sudden accidents can also induce network coverage failure in some areas. The most common method to maximise the network coverage in mine roadways is to increase node density, which can not only result in increased costs of system construction and operation, but also lead to increased network management complexity. Therefore, it is imperative to investigate new paradigms of wireless network design for use in mines.

Intermittent or regional connection does not mean absolute or permanent failure of communication between the transmitting and receiving nodes[15]. The negative effects of unstable link quality will be substantially offset by a communication system with the ability to dynamically cognise environmental features and self-adaptively adjust communication parameters based on the results of cognition[16], reducing the probability of intermittent or regional connection. Considering that node movement creates a meeting opportunity for nodes located in different regions, data can be transmitted to other nodes that are more likely to meet the target node even in the case of intermittent or regional connection; such information can then be stored, transported, and forwarded for delivery to the target node[17]. An opportunistic communication network based on cognition of the mine environment can adapt to the dynamic advancement and vulnerability of mining nodes and is thus of great significance to improve successful communication.

At present, few studies have been reported which investigated self-adaptive mine communication based on opportunistic communication. Ji Luo conducted a study on delay tolerant communication in coal roadways[11], in which the tramcar in the mine roadway was used as a mobile sink node, and the sensors deployed in the roadway remained stationary; the tramcar moved along the deterministic path in the roadway to directly collect data from sensor nodes, thus avoiding multi-hop transmission. However, this study only considered the specific circumstances of a moving tramcar and stationary nodes, while practical applications must also consider the moving nodes which represent underground miners. The reported study also failed to consider the effects of dynamic changes in the physical communication space and did not address the environmental self-adaptation problem in mine roadways, thus failing to address the challenges posed by intermittent or regional connection.

Three key problems must be addressed to implement cognitive opportunistic mine communication:

1. The establishment of the node mobility model based on the node movement characteristics and spatial constraints of mines: this model will serve as the basis for cognition of the mine environment and the implementation of opportunistic communication. The difficulties implementing this model include the state transition mechanism and performance bounds of the model, its concordance with actual motion, influential factors, and their interaction mechanism of the model

2. The dynamic determination of optimum parameters for communication links to reconfigure the communication system automatically: this is essential to the environmental self-adaptation of wireless communication systems for mines and to the reduction of intermittent or regional connection. The main challenges are the modelling of the joint optimisation to dynamically determine and configure the optimum communication parameters.

3. The design of opportunistic routing algorithms accurately reflecting the characteristics and requirements of mines based on the influential factors of transmission performance and their operational mechanisms: this is necessary to relatively stable data transmission of wireless communication systems for mines under intermittent or regional communication conditions. The challenge presented by this problem is that there are too many factors which must be considered when designing such type of algorithms.

Here an opportunistic mine communication framework is proposed; see **Figure 2**. First, historical data of node movement achieved by positioning systems are used to determine and analyse node meeting characteristics such as the interval and duration of node meetings. The work arrangement of mining crews is utilised to investigate the groups to which different personnel belong. The fourteen cognition results of environmental parameters are exploited to obtain contextual information regarding the node circumstances. The analyses described above as well as the physical roadway structure make it possible to construct the node mobility model. Second, a node timely determines the available channels between itself and its neighbour nodes according to the perceived environmental parameters. Based on the monitoring requirements of the ground monitoring center and channel estimation results of mine roadway, the communication system parameters are adjusted to implement its self-adaptation to the mine environment. Finally, based on the established node mobility model and the results of

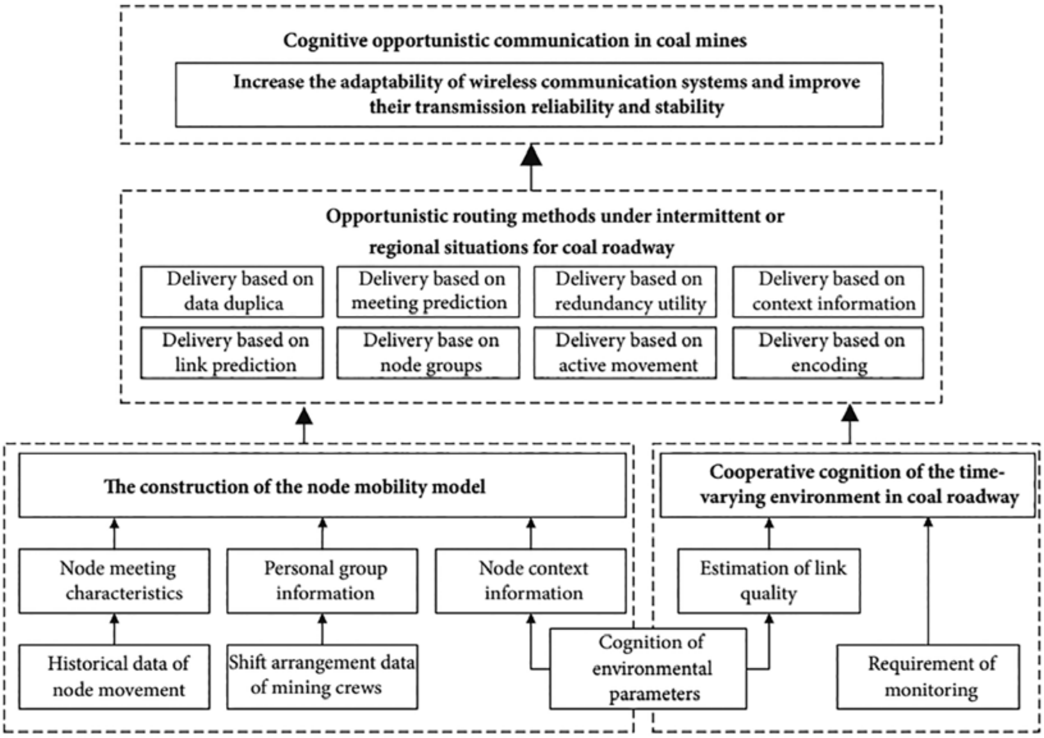


Figure 2: Cognitive opportunistic communication framework for coal mines.

communication environment cognition, the opportunistic communication mechanism of mine roadways can be investigated, and effective opportunistic routing algorithms can be designed to implement stable data transmission under regional or intermittent connection conditions.

To address the challenges faced by the proposed architecture, Section 3 will discuss the construction of the mobility model for moving nodes in mine roadways, as well as cooperative cognition of the time-varying communication environment and the opportunistic routing of intermittent or regional connection scenarios.

Construction of the Mobility Model for Mobile Nodes in Mine Roadways.

Data transmission in a mine roadway is primarily affected by transmission distance, the node mobility model. and neighbour scanning frequency[18]. Additionally, much data is closely related to the contextual information of nodes and demonstrates strong temporal or spatial characteristics[19]. Therefore, discovery of neighbours, the perception of node mobility, and construction of a mobility model serve as the foundations for environmental cognition. The fourteen synchronous neighbour discovery methods are not appropriate for a mine roadway because the assumption of one node transmitting and one node receiving does not necessarily hold true, particularly in a coalface. It is essential to carefully investigate the scanning frequency of neighbours to make a trade-of between energy consumption and information timelines.

Mobility models are the basis for movement perception and the design of a routing algorithm. Current studies of mobility models have primarily focused on discovering the distribution characteristics of meeting intervals and durations[20] and the establishment of network sequential diagrams reflecting changes of network topology[21]. Experimental data have also been used to study the characteristics of information transmission paths to determine the temporal-spatial correlation between nodes[22].

Traditional mobility models based on random movement assume that both destination and velocity are random; this is characterised as Brownian motion, such as that employed by the random waypoint model (RWP) and random walk model (RWM).This type of mobility model facilitates the theoretical derivation of performance bounds; it is very flexible and its movement characteristics can be extended by making changes to the model parameters. However, this type of model cannot capture the actual movement patterns of moving objects in mine roadways. The fourteen tramcar, shearer, and hydraulic support in a mine roadway move according to a highly regular pattern, but the movement of a miner is both regular and random due to the constraints of their job types and working hours. Existing mobility models cannot fully reflect these characteristics, and further study must be conducted to explore the mobility models of nodes based on the characteristics of mine roadways to provide guidance for the design of opportunistic routing algorithms.

First, the existing positioning system is used to collect the location and time information of the moving nodes in the mine roadway to obtain historical datasets of node movement (**Figure 3**). The status distribution and meeting intervals and durations of nodes at a given moment reflect the temporal and spatial characteristics of opportunistic networks, which are of great significance to data transmission. These studies help solve[23,24] (1) which nodes frequently meet the current node and are thus candidates for relay selection; (2) which nodes have social and group connections which may indicate a greater willingness to communicate cooperatively; and (3) how long a meeting lasts, in which an optimal time value will allow complete yet efficient communication. A mobility model can then be designed based on the obtained statistical characteristics.

For example, the movement of nodes in a mine roadway can be modelled as a temporally correlated Markov process, which is then validated by experimental data. If the states of a message located at node and node are called current state and next state, respectively, then its transition from the current state to the next state corresponds to a data transmission scenario. The period spent awaiting the transition from one state to another represents the meeting interval, and the period spent in the designated state represents the meeting duration. Different states correspond to different mine locations, and state transitions correspond to location migration. Transitions into and out of the same state demonstrate identical movement characteristics, while transitions between different states demonstrate different movement characteristics. A feedback mechanism can be introduced to the state transition process to mitigate the fluctuation of motion patterns in different locations. Node mobility can thus be perceived, and node movement can be predicted based on the node mobility model and node discovery mechanism.

Cooperative Cognition of the Time-Varying Communication Environment of Mine Roadways

Due to the dynamic changes in the physical space and the harsh working conditions of mines, the wireless links in mine roadways are subject to sudden, significant changes, which

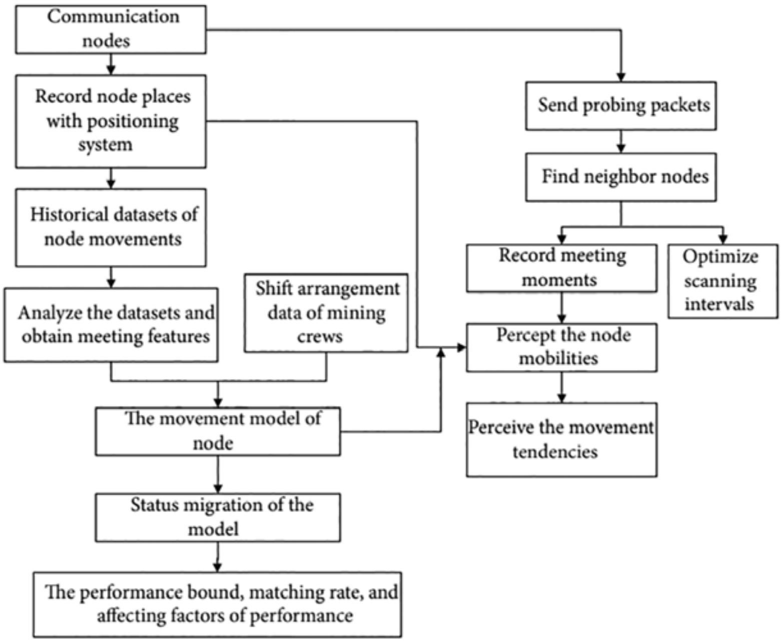


Figure 3: Construction of the mobility model for model for mobile nodes in mine roadways.

can result in the loss or increased delay of data. Environmental cognition helps enhance the adaptation of communication systems to environmental changes. Once link quality reduces, the communication system can adjust its parameters to adapt to the current surroundings to avoid intermittent connection. For this purpose, it is essential to estimate the link quality in real time[25] to adjust the communication parameters to optimum values in a timely manner. For example, the power of transmission systems can be improved to increase the one-hop transmission distance to improve the success ratio of data transmission under poor link quality or relay failure conditions.

However, higher transmission power also results in greater energy consumption and leads to greater interference to neighbours on the same frequency[26]. A self-adaptive power control algorithm may be designed to reduce energy consumption (**Figure 4**) and to enable nodes to establish and maintain connection using minimum power requirements. Power control and channel selection must be jointly optimised to reduce interference[27] and must be designed as a distributive, dynamic algorithm which may employ game theory, or the machine learning method based on local node information such as local signal-to-noise ratio. Both environmental cognition and parameter adjustment require that nodes engage in explicit or implicit information exchange when they meet[28], leading to a cooperative mode based opportunistic cognition and adjustment. To implement environmental parameter cognition, nodes must effectively perceive the communication environment and adjust parameters based on the environment, user goals, and node capabilities[29].

However, it must be noted that environmental cognition cannot be equated with environmental perception; the latter simply involves parameter acquisition, while the former involves decision-making based on perceived information[30], even in situations in which the acquired environmental information is incomplete.

Opportunistic Routings of Intermittent or Regional Connection Scenarios in Mine Roadways.

If the decline of data transmission performance does not result from the link degradation but from link interruption, the studies described above will not be enough to ensure data transmission. As a possible solution, node movement characteristics and the spatial constraints of mine roadways must be explored to design an efficient opportunistic routing method. In the field of opportunistic routing, existing studies have extensively focused on the forwarding mechanism based on a message replica. This forwarding mechanism creates a balance between transmission delay and resource consumption by controlling the number of copies[31] or calculates the probability of node meeting based on historical information and link prediction before forwarding the data to the nodes that are more likely to meet the destination node[32].

Node movement in a coal mine consists of highly correlated cooperative movement that seeks to accomplish production goals. In the coalface, a shearer driver operates the shearer to cut coal, and the hydraulic supports advance to support the roof during the mining process. The mined coal is then transported to the belt via the scraper conveyor and then

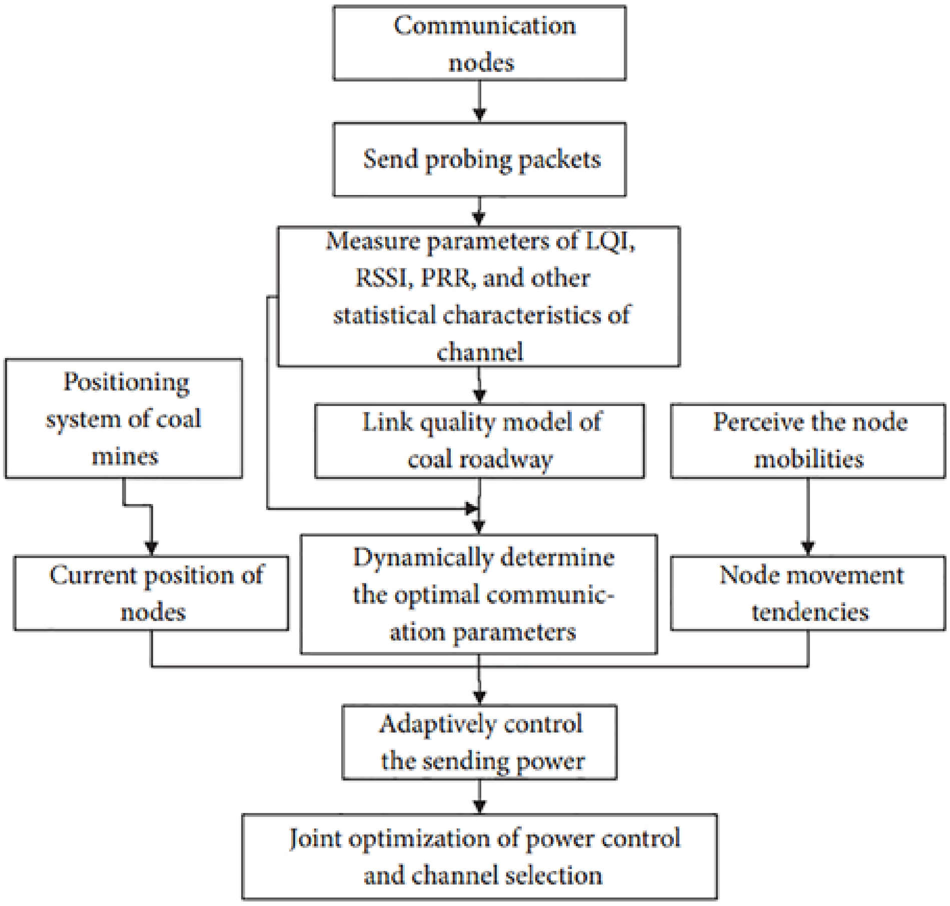


Figure 4: Cooperative cognition of the time-varying communictin environment of mine roadways.

lifted onto the ground after transportation via the belts or tramcars. This overall process involves driving, mining, transportation, ventilation, and drainage and thus requires a great number of personnel and lots of equipment. The movement of the equipment and personnel includes both regular movement (such as that exhibited by the shearer, hydraulic support, and tramcar) and mixed regular and random movement, such as the movement of the operators. Overall, most node movements in mine roadways are characterised as regular movement. With the help of mobility models, opportunistic routing algorithms can be designed based on meeting prediction, copy distribution, and context distribution mechanisms; see **Figure 5**.

Additionally, nodes in a mine roadway often transmit data in a linear, directional manner. For example, the data transmission of the coalface always heads to the sink node in the headgate or tailgate. Therefore, it is appropriate to design an opportunistic routing algorithm based on geographic locations. The fourteen tramcars and personnel which partake in cyclic reciprocating motion provide opportunities for data transmission between nonadjacent equipment and personnel which can serve as the ferry node between disconnected nodes. Furthermore, the established node mobility model incorporates historical meeting information and node meeting characteristics. Based on these various characteristics, different utility indicators can be designed for opportunistic transmission. According to the results of communication environment cognition, a set of relay candidates can be determined for the current node in order to implement opportunistic transmission based on link prediction's success of message transmission as well as the energy consumed by transmission is greatly affected by the number of nodes in a mine roadway, the number of messages to be transmitted, and message size. Finally, the parameters of the physical layer, link layer, and network layer can be combined[33] to design cross-layer opportunistic routing algorithms.

AN EXEMPLARY APPLICATION: PERSONNEL EVACUATION BASED ON COGNITIVE OPPORTUNISTIC COMMUNICATION IN AN EMERGENCY

Cognitive opportunistic communication is of great significance to the mobile acquisition of mine environmental information as well as the continuous monitoring of miners' health information, particularly to disaster prevention and reconstruction of a mine internet of things designed for ordinary activities. As an example, this section discusses the application of cognitive opportunistic communication to the transmission process of disaster information in an emergency, such as a coal mine food, the presence of excessive gas, and production accidents. In case of an emergency, the sensor node (carried by a person) which first perceives the emergency must quickly transmit the information about when and where the accident took place and the urgency degree of the accident to nearby personnel and instruct personnel to evacuate as quickly as possible, as shown in **Figure 6.**

However, some nodes in the accident region may not be in normal working status because of the emergency, making the accident information incapable of being transmitted. However, the sensor nodes carried by moving objects (e.g., personnel or vehicles) can detect the accident information and subsequently transmit the information through cognitive opportunistic communication during evacuation.

1. The first person who perceived the emergency will first evacuate from the area of danger. As more people are met during the evacuation and information is exchanged, more people will evacuate. In this way, information is diffused during the evacuation process
2. A vehicle typically moves in a periodic motion along a determined path at a determined rate to transport goods or personnel. If no person is in the vehicle, the vehicle will continue to move until it meets a person to which it will forward information regarding the accident. If a person is present in the vehicle, the person can choose to evacuate by the vehicle continuously or get off and evacuate on foot.

Emergencies that occur in a mine roadway often affect one or more areas of the roadway rather than a single place, such as in the case of a coal mine flood or the presence of excessive gas. Therefore, personnel must move toward a designated safe area. For example, as shown in **Figure 6**, there are four designated evacuation routes. Following route 1, a person can evacuate directly along the upper oblique

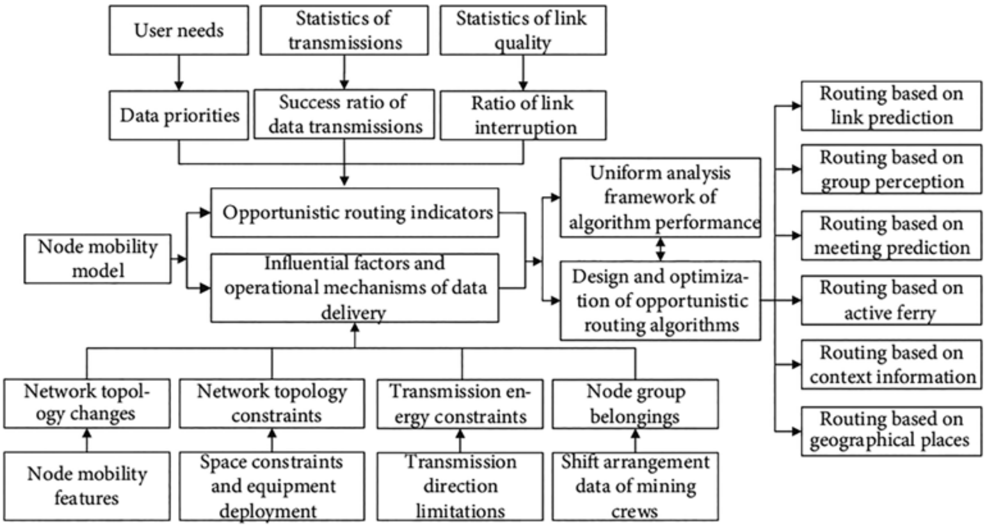


Figure 5: Opportunistic routings of intermittent or regional connection scenarios in mine roadways.

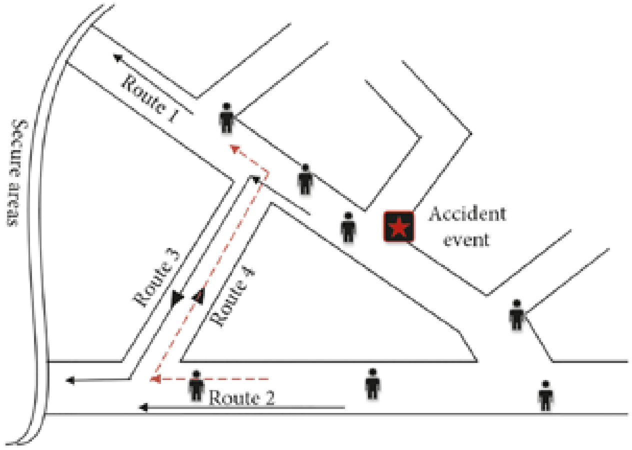


Figure 6: Personnel evacuation under emergency scenarios.

straight roadway; following route 2, a person can evacuate directly along the lower long straight roadway; following route 3, a person can evacuate along the lower roadway after passing through the upper roadway and the middle roadway; following route 4, a person can evacuate along the upper oblique straight roadway after passing through the lower roadway and the middle roadway. In an actual mine roadway, different roadway combinations may generate many escape routes; a person can evacuate quickly and safely only by following a designated optimum path.

As the popularity of the mine internet of things increases, personal terminals used for perception in mines have developed increasingly diverse functions and strong computing capabilities . A roadway map can be stored in personal terminals and advice about best escape routes can be offered in case of an accident, based on the perceived information of the accident scenario. A circumstance in which all personnel evacuate along the same route should be avoided to avert congestion or collision, and the cognitive opportunistic abilities of the communication system can recognise the mine environment in real time to plan, guide, and proactively evaluate optimum escape routes and to ensure balanced traffic distribution. This indicates that cognitive opportunistic mine communication is of great importance to accident information spread and evacuation path optimisation in an emergency.

It must be noted that all personnel who follow the feasible escape routes from the accident location to the pithead must receive information about the accident. However, personnel in roadways that are positioned directly opposite the escape paths cannot receive information about the accident because they cannot encounter any moving objects with the event information. This problem can be addressed from the following perspectives:

1. Mine trunk roadways are typically covered by wired industrial networks, while some of these roadways are also covered by Wi-Fi wireless networks and opportunistic communication is typically implemented at the endpoint of a coal mine such as the coalface. If an accident occurs at the endpoint of a coal mine, personnel nearby will see or hear the accident, prompting themselves to shout to warn others of the accident. As a result, all personnel in this region can quickly evacuate, prohibiting a circumstance in which the location of the accident cannot be communicated

2. If an accident occurs in an area covered by a traditional wireless network (such as a Wi-Fi, 3G, or 4G network) resulting in damage to some aspects of the wireless network, personnel in the underground coal mine will form an opportunistic network during evacuation, while personnel located behind the accident location can receive accident information via the mixed network

3. If a person is evacuated to a region effectively covered by a network, the accident message can be transmitted to the ground control center via the backbone network, which then notifies all underground personnel of the accident situation via voice broadcast or direct transmission of the message to personal terminals. Of course, if an area of a roadway collapses, the miners behind the area of the roadway cannot evacuate and must wait for rescue no matter whether they have perceived the accident situation or not .

CONCLUSIONS

The communication parameters of wireless mine communication systems, such as communication participants, signal transmission environment, and node mobility model, greatly differ from those of ground wireless communication systems. Cognitive opportunistic means, therefore, play crucial roles there, because their self-adaptive recognition mechanisms for mine environments and the opportunistic communication abilities keep communication systems informed about the time-changing environmental or communicational parameters. Keeping this issue in mind, we proposed a novel wireless communication framework for coal mines based on the cognitive opportunistic communication of the internet of things, which includes three key elements, namely, the node movement model constructing, the cooperative cognition of time-varying communication environments, and the opportunistic routing of intermittent or regional connection scenarios. Eventually, an example of personnel evacuation under an emergency scenario was explored to validate the usage of this framework. Subsequent studies will involve the theoretical investigation and field experiments based on the movement data collected from mine nodes, as well as the design of practical node mobility models, routing methods, and the system prototype of the cognitive opportunistic communication system for mines.

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The publisher has added all additional images.

Conuma Resources restarts operations at Quintette Mine after 24-year absence

A Tumbler Ridge coalmine that closed its doors 24 years ago has been re-opened by Conuma Resources.

Operations restarted recently at the Quintette Mine according to Minister of Energy and Mines Josie Osborne.

“The mining and mineral exploration sector is a foundational part of British Columbia’s economy, providing more than 40,000 good, family-supporting jobs – and we’re supporting it to grow.

“Government continues to take action to streamline the mine-permitting process while maintaining our world-leading standards for worker safety and environmental protection. Permitting wait times have been a long-standing issue for the sector, and I am pleased that the hard work of ministry staff has resulted in average review timelines for major project permits being reduced by more than one-third in the past five years. The approval process to restart Quintette’s Little Windy Pit was completed in just over four months.”

The mine is expected to employ over 400 people in the area according to the province.

BC’s mining and mineral exploration sector provides over 40-thousand jobs with employment increasing by 10% since 2017.

Mine water could heat thousands of Welsh homes

Energy bills could be cut by low carbon heat schemes which use water from abandoned Welsh coal mines.

One in five properties in Wales lies above an area which has the potential for a mine water heat scheme, the Coal Authority said.

The temperature of accessible mine water ranges between 10 and 20C depending on the depth.

Work is under way to look at developing mine water heat projects in Rhondda Cynon Taf, Caerphilly and north east Wales.

The Welsh government said it was investing in different types of low carbon heat projects to meet the energy demand of the future.

The Coal Authority estimates about two trillion litres of warm water occupy old mine shafts across the UK.

As a result, it considers mine water to be one of the best options to help with the decarbonisation of heating.

Natural gas remains the primary source for heating but the Welsh government has committed itself to reduce its greenhouse gas emissions to zero by 2050.

Research has been carried out by the Coal Authority on old mine workings across 11 local authority areas to asses the potential for mine water heat projects.

Gareth Farr, who leads the Coal Authority's mine water heat project in Wales, said they hope to replicate the success of the UK's first large scale mine water heat scheme in Gateshead.

"Since the closure of a lot of the collieries, they've filled up with water so these schemes operate by us drilling bore holes down to intercept that water," he said.

"It's then brought to the surface and heat exchangers recover heat from the water which is returned safely below ground. The heat we recover is distributed through heat networks to homes, offices or industrial units.

"From mine water heat in the north east of England, it has shown to be delivering heat at 5% below the gas heat price to customers, so that is really important especially during a cost of living crisis."

Ffynnon Taf primary school in Taff's Well, Rhondda Cynon Taf, is an example of a small-scale local heat scheme where the village's natural thermal spring is used to heat the school's building and a pavilion in the park.

But other community based heat schemes in Wales have not had the same success to date.

A feasibility study for a project in Caerau, Bridgend, was carried out a few years ago in the hope it would benefit homes and a school, but the local authority scrapped the project due to cost. It said it would look at alternative options in the future.

The Coal Authority said it was important to learn from national projects which have succeeded.

Scott Morrison, from the Glasshouse International Centre for Music in Gateshead, said it has saved tens of thousands of pounds since it joined the town's mine water heat scheme in spring 2023.

Five kilometres of pipes supplies homes, businesses and public buildings with heat throughout the year.

"Because we're a large building, our energy bills are one of our biggest annual costs.

"The other benefit is we're also aiming to be net zero by 2030 so we're trying to make a serious response to the climate crisis and this really helps us reach that target," Mr Morrison said.

In a statement Ken Skates, Cabinet Secretary for Economy, Transport and North Wales, said: "With heating accounting for 50% of energy use in Wales, mine water heat could improve the sustainability of the places where we live and work.

"Mine water heat could also play a part in our necessary efforts to tackle climate change and support decarbonisation.

"By looking at projects such as mine water heating, as well continuing to make strides in the delivery of a swathe of other renewable energy schemes, there is every reason to be optimistic about our future as global leaders both in the adoption and creation of cleaner energy and the technology that facilitates it.”

Research on an intelligent mining complete system of a fully mechanised mining face in thin coal seam

The mining environment of thin coal seam working faces is harsh, the labor intensity is high, and the production efficiency is low. Previous studies have shown that thin coal seam mining finds it difficult to follow machines, does not have complete sets of equipment, has a low degree of automation, and has difficult system co-control, which easily causes production safety accidents. To effectively solve the problems existing in thin coal seam mining, Binhu Coal Mine has established intelligent fully mechanised mining and actively explored automatic coal cutting, automatic support following, and intelligent control. The combination of an SAC electro-hydraulic control system and SAP pumping station control system has been applied in 16,108 intelligent fully mechanised coal mining faces, which realises the automatic following of underground support and the control of adjacent support, partition support, and group operation; the automatic coal cutting of the shearer is realised by editing the automatic coal-cutting state of the shearer and adjusting the automatic parameters. A centralised control center is set up, which realises the remote control and one-button start–stop of working face equipment. Through a comparative analysis of 16,108 intelligent fully mechanised mining faces and traditional fully mechanised mining faces, it is found that intelligent fully mechanised mining faces have obvious advantages in terms of equipment maintenance, equipment operation mode, and working face efficiency, which improve the equipment and technical mining level of thin coal seam. The application of intelligent mining in Binhu Coal Mine has a great and far-reaching impact on the development of thin coal seam mining technology in China.

The coal resources in thin coal seam are widely distributed, however, its output is far lower than the proportion of reserves, resulting in an imbalance between outputs and reserves, and some resources have not been mined for a long time. To improve the utilisation rate of resources, ensure the balance of mine production capacity, and realise the sustainable development of mines, it is necessary to mine thinner coal seam reserves and implement “thin–thick” and “fat–thin” matching mining.

With the continuous exploitation of coal resources in eastern China, the proportion of coal resources in western China is rising. By 2020, the proven recoverable reserves of thin coal seams were about 600 million tons, accounting for about 20% of the total coal reserves in China, and most of the thin coal seam resources are concentrated in the central and western regions of China, such as Sichuan Province, whose thin coal seam resources account for 51.8% of the coal resources in this province; Shanxi Province is one of the provinces with the richest thin coal seam resources in China. Thin coal seam resources account for 17.6% of the province’s coal resources, and the mining reserves of thin coal seam are 1.38 billion tons, distributed in Datong, Ningwu, Hedong, Xishan, Luliang, Wutai, and Xinzhou; the thin coal seam resources in Shandong Province are distributed in Xinwen, Longkou, Yanzhou, Zaozhuang, and Jining. Thin coal seam resources account for 16.8% of the coal resources in Hebei Province, distributed in Xingtai, Handan, Zhangjiakou, Chengde, and other areas; the thin coal seam resources in Anhui Province are distributed in Huaibei, Huainan, Suzhou, and Fuyang.

There are many problems and inconveniences in thin coal seam mining, such as a bad working face environment and low and narrow working face space. As a result, people cannot walk upright, labor intensity is high, there are many gangue faults, and some working faces cannot even enter. Moreover, it is difficult to follow machines and repair the equipment, which easily causes production safety accidents. Therefore, the automation and intelligence of equipment and technology are the key and inevitable choice to realise the safe and efficient mining of thin coal seam, and it is also the development direction of modern mine construction. According to the actual situation of thin coal seam mining in the Western Donbas mines, a new progressive method is put forward, which can effectively reduce the output of gangue, reduce the pollution to the environment, and bring about remarkable economic benefits. In addition, the coal industry is gradually developing from manual coal mining and semi-mechanised coal mining to mechanised, comprehensive mechanised, and automatic coal mining, and has begun to move forward from automatic mining to intelligent mining. With major breakthroughs in new generation information technologies such as 5G communication, big data, and Internet of Things, the upgrading and transformation of the coal mining mode from automation to intelligence has received technical support. The concepts of smart coal mines and intelligent mines are gradually becoming clear, and the standards and specifications are gradually being completed, which lays a foundation for their large-scale popularisation and application.

Currently, domestic, and international experts and scholars have extensively explored and researched intelligent coal mining, yielding abundant results. Wang reported an intelligent system for mechanised mining equipment with Chinese independent intellectual property rights. An intelligent mining model was established to realise unmanned operation and single person inspection at the working face. Basarir and Massinaei achieved the intelligent, fully mechanised mining of super-thick coal seams. This was accomplished using hydraulic caving support for high-top coal in large-scale mines, an intelligent coal tunnel system, and crucial intelligent control technology, thus providing reference for the intelligence-led construction of deep, thick coal seam. Tian put forward five key research and development directions of intelligent coal mines, analyzing the key technical problems involved in each research and development direction. They pointed out that intelligent coal mines are large-scale systems, and they should follow the theory of system engineering and mining law to develop the integrated management, development, and operation platform of an intelligent coal mine giant system. Shen summarised the four stages of intelligent mining, analyzed the production traits and technical prerequisites at different stages, proposed a control theory model within the intelligent adaptive mining technology mode, and advanced towards intelligent mining using essential new technologies. Yang, in order to solve the problem of large mining height comprehensive mining faces with many workers and a high labor intensity, analyzed the technical difficulties such as the precise control of rib spalling, soft underframe and equipment reliability, perception accuracy, poor coordination, and other technical difficulties in the intelligent comprehensive mining of large mining height working faces. The visualisation remote intervention technology route was adopted to realise the intelligent normal mining of a large mining height comprehensive mining working face, which achieves the purpose of reducing personnel and improving efficiency. The article proposed using an energy-based principle of ground control in a fully mechanised longwall, which means the adjustment of the volume of power fluid by-pass from the head ends of the hydraulic props of the powered support units to the pressure line of the hydraulic system of the fully mechanised longwall mining system during the subsidence of roof rocks. Wu studied the current situation and development trend of intelligent mining technology in a comprehensive mining face and divided the intelligent mining technology in the comprehensive mining face into two stages, namely, intelligent unmanned mining in the visualisation remote intervention mode and intelligent unmanned mining in the adaptive mode. He believes that mine large section roadway deformation intelligent control technology, mine tunneling machine intelligent technology, anchor bracket intelligent technology, transportation system intelligent technology, and video monitoring intelligent technology will be the key technologies of comprehensive mining face. Reflecting on the current state of visual remote intervention, robot-assisted inspection, and inertial navigation technologies, Huang introduced four-dimensional intelligent coal mining system infrastructure which encompasses “perception, decision-making, execution, and operation and maintenance.” Furthermore, they outlined the technological advancements necessary to progress key intelligent coal technologies. This plays an important role in building an intelligent mining system. Similarly, Zhan, in order to improve the degree of automation and intelligence of longwall mining, in response to the problems of unknown information of the mining area and the insufficient objectivity of decision making in the production process during the construction process of some intelligent coal mining enterprises, proposed a four-aspect global model for the construction of a transparent longwall mining face on the basis of analyzing the special requirements of automated mining in coal mining enterprises. The structure of the whole transparent longwall mining face was designed from the four dimensions of intelligent application, informatisation, transportation, and sensing. This has good reference significance for the system design of intelligent working faces in thin coal seam. Si, by studying the intelligent production mode and status quo of intelligent technical equipment, presented the subsequent focus areas for intelligent technical equipment in fully mechanised mining faces. These research efforts primarily targeted the intelligent mining of substantial coal seam and top-coal caving faces. However, when compared to vast coal seams, the mining conditions of thin coal seams are more complex due to the lower thick bottom of the coal seam and significant variance in angles, folds, and faults. Bołoz introduced, in detail, the common mining methods in thin coal seam underground mining and the disorders in the mining machines used in the methods of Highwall, Auger, and Punch longwall mining, along with their types and variations. The article proposed a constructive technical solution to increase the contact adaptivity of the mechanical roof support. The developed solution of the mechanised support section can adapt to changing mining and geological conditions in the process of the excavation of the mining pillar, which increases the efficiency and safety of coal excavation in the longwall. Additionally, the intelligent development process faces numerous issues such as ambiguous concepts and technical connotations and indistinct mining modes and technical routes, among others.

Analysing the above, intelligent mining is a hot issue. This paper synthesises the advantages of domestic and foreign thin coal seam mining technology, aiming at the intelligent mining of fully mechanised coal mining faces in thin coal seam, actively explores automatic coal cutting, automatic support following machines, and intelligent control, and realises the linkage control of coal cutting, traction, transportation, and support moving. Finally, the production automation, intelligent coal cutting, information management,

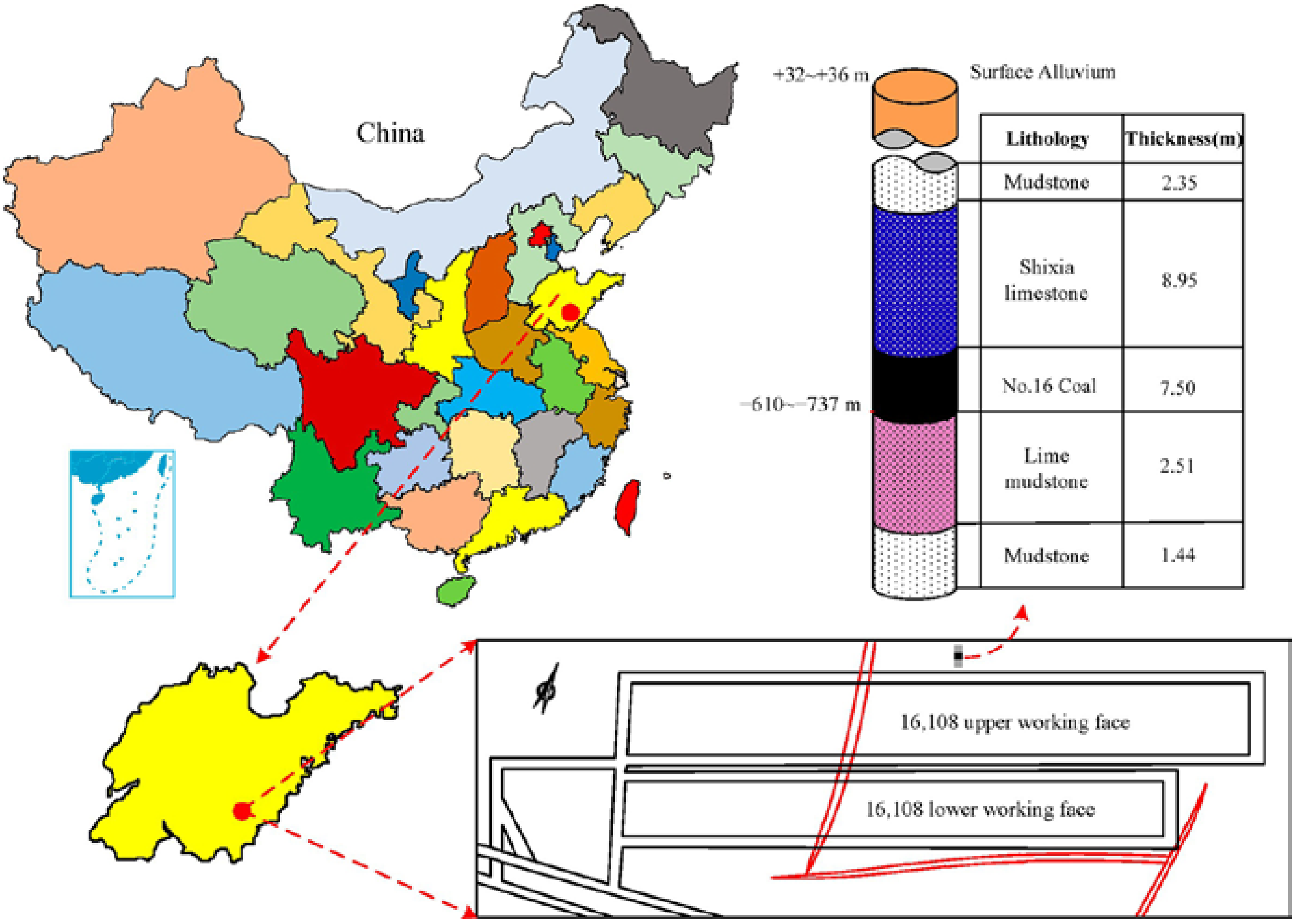

Figure 1: Location map of working faces.

and unmanned working faces of thin coal seam mining are realised.

GENERAL SITUATION OF INTELLIGENT FULLY MECHANISED COAL MINING FACE IN THIN COAL SEAM

Geological Conditions

The 16,108 intelligent fully mechanised coal mining faces in Binhu Coal Mine are in 161 mining areas, mining sixteen coal seams of the Taiyuan Formation of Upper Carboniferous. The ground elevation of the working face is +32~+36 m, the working face elevation is −610. 0~−737.0 m, the average buried depth is 707.5 m, the coal seam thickness is 1.10~1.45 m, and the average thickness is 1.29 m. The strike length of the working face is 1400 m, and the inclined length is 220 m, as shown in **Figure 1**. The occurrence state of the coal seam is stable, the strike of coal seam is 167~199, the dip is 257~289, and the occurrence is gentle. The direct roof of the working face is ten lower limestone, with vertical fissures developed, the roof condition is hard, and the floor is sandy mudstone, which is semi-hard and complete. The main structure of 16,108 intelligent fully mechanised coal mining faces in Binhu Coal Mine belongs to a monoclinic structure, and the average dip angle of the coal seam is eleven. No fold development is found from the exposure of two roadways, and only one fault is exposed, with a drop of about 1.5~5.5 m.

Intelligent Mining Equipment Matching of Fully Mechanised Coal Mining Face in Thin Coal Seam

The intelligent and fully mechanised mining face of the Binhu Coal Mine 16108 is equipped with the MG400/870-WD double drum shearer produced by Shandong Zhongmei Intelligent Equipment Co., Ltd., the SGZ764/500 scraper conveyor produced by Shan-dong Xingye Machinery Accessories Co., Ltd., and the SZZ730/160 bridge conveyor pro- duced by Luoyang Yuanjian zMining Equipment Co., Ltd. A total of one hundred supports were selected for the intelligent and fully mechanised mining face of 16108, with ninety-six units of ZY400/09/18D electro-hydraulic control hydraulic supports as the main supports, and four units of ZT400/12/24YD electro-hydraulic end supports, all produced by Jining Huaming Mining Machinery Equipment Co., Ltd.

The reliability of equipment should be considered in the equipment matching of intelligent fully mechanised coal mining faces in thin coal seam. First, whether it can meet the requirements of an intelligent fully mechanised coal mining face to produce 1.1 million t/a; the second is to ensure that the selection of various equipment should be reasonable, ensure the reliability and stability of the coal flow system, and ensure the rapid advancement of the working face; and third, whether the equipment of the working face and transportation lane can realise coordinated and centralised control. The equipment models of the 16,108 intelligent fully mechanised coal mining faces and transportation roadways are shown in **Table 1**.

INTELLIGENT MINING SYSTEM OF FULLY MECHANISED COAL MINING FACE IN THIN COAL SEAM

The intelligent mining system of a fully mechanised coal mining face in a thin coal seam of 16,108 working faces includes an electro-hydraulic control system of hydraulic sup- port, automatic coal cutting and video monitoring system of shearer, intelligent integrated liquid supply system, and remote centralised control system. A total of 16,108 intelligent fully mechanised coal mining faces realise automatic support moving through the electro-hydraulic control system, and display and monitor the position of shearer and support in real time through sensors installed on the shearer and support, so as to ensure that the support automatically moves with the shearer, realising the automatic coal caving of the support by using the time parameters and stroke height of the swing beam. Through the automatic coal cutting of the shearer and video monitoring system, the coal cutting state of the shearer is edited and the position and direction of the shearer (upward or downward) are monitored to realise the automatic coal cutting of the shearer according to coal mining technology. The intelligent linkage of multi-pumping stations and remote multi-machine control are realised through intelligent integrated liquid supply and a remote centralised control system. In a word, the working face adopts a variety of sensors, and realises the realisation of equipment in the whole working face through program control. The coordinated management and centralised control of equipment in the comprehensive mechanised coal mining face make the equipment run continuously, efficiently, and safely. The composition of the intelligent mining system in a fully mechanised coal mining face in thin coal seam is shown in **Figure 2**.

Table 1: 16,108 intelligent fully mechanised mining face and transportation roadway equipment model.

Equipment Name	Equipment Model	Quantity	Whether It Is Automatically Controlled or Not
Shearer	MG400/870-WD double drum type	1	Yes
Hydraulic support	Model ZY4000/09/18D	96	Yes
	Model ZT4000/12/24YD	4	Yes
Scraper conveyor	Model SGZ764/500	1	Yes
Bridge loader	Model SZZ730/160	1	Yes
Crusher	PLM1000	1	Yes
Emulsion pump	Model BRW400/37.5	2	Yes
Spray pump	Type BPW-320/12.5	5	Yes
Water purification equipment	Model JXGSZ-70JB-4A	1	Yes

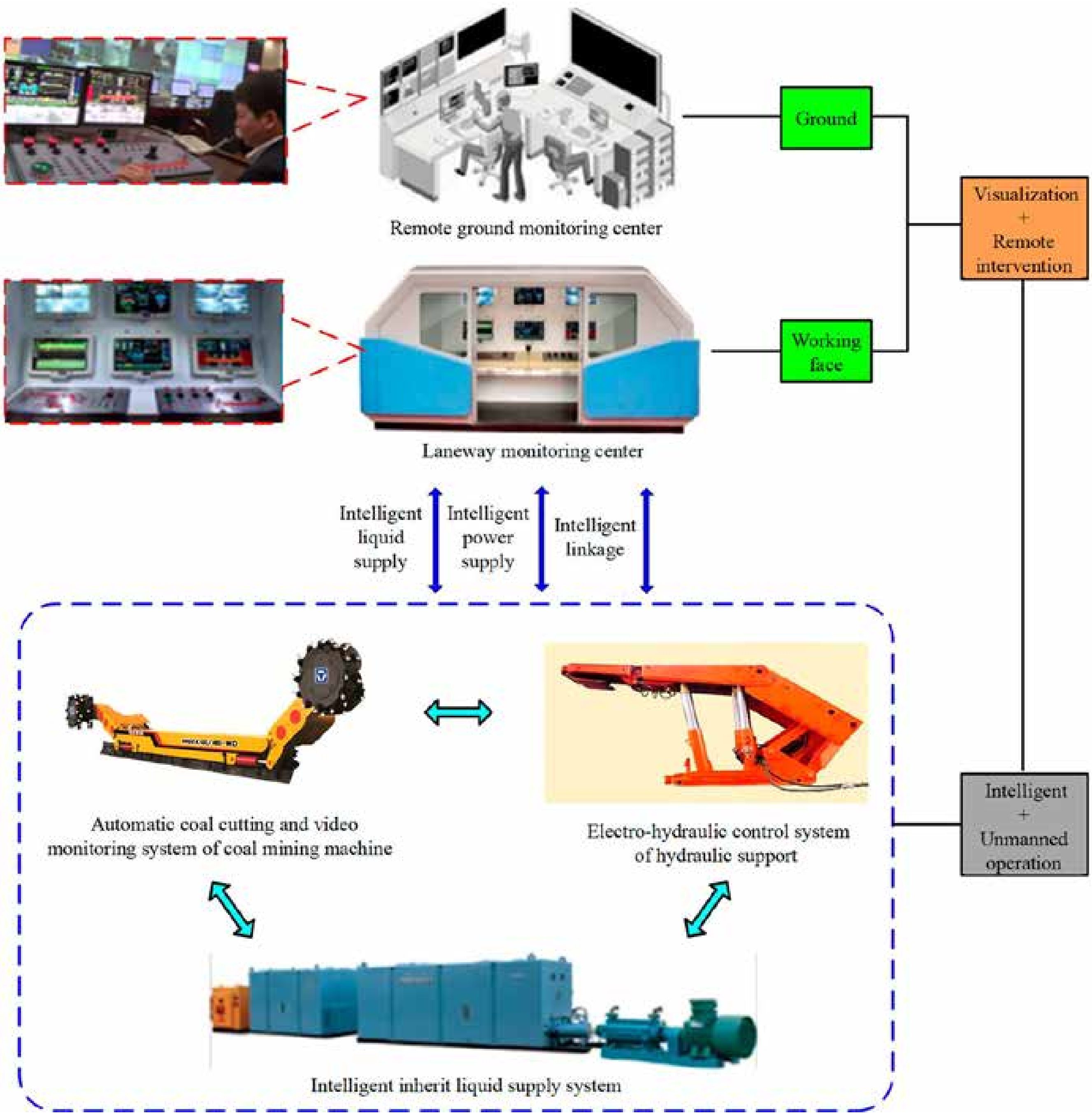

Figure 2: Composition of intelligent mining system for fully mechanised coal mining face in thin coal seam.

Electro-Hydraulic Control System of Hydraulic Support

The electro-hydraulic control system of hydraulic support adopts an SAC electro- hydraulic control system, which is composed of three aspects, as shown in **Figure 3**.

1. All basic frames of the 16,108 intelligent fully mechanised coal mining faces are equipped with one controller, eight sensors, one driver, and one electro-hydraulic control valve group, which, together, constitute the most basic control unit. The controller is the core of the control unit. It is a microcomputer which is equipped with operating software and a human–computer interaction interface. It is a platform for employees to operate. The detection link includes five types and eight kinds of sensors, which are front and rear column pressure sensors, infrared receivers, push stroke sensors, guard proximity sensors, inclination sensors (main top beam, shield beam, and tail beam), and rear swing beam stroke sensors. The executive link includes a driver and an electro-hydraulic valve group, which drives the retracting and extending actions of various supports.

2. All support controllers in the 16,108 intelligent fully mechanised coal mining faces are interconnected to form a communication network system, and data communication among controllers is realised by bus technology. After the controllers are interconnected, the main functions such as adjacent/separated support control, remote control, single support or group automatic control, emergency stop of the whole line, state, and fault information display, and so on are realised. The SAC system is equipped with the necessary

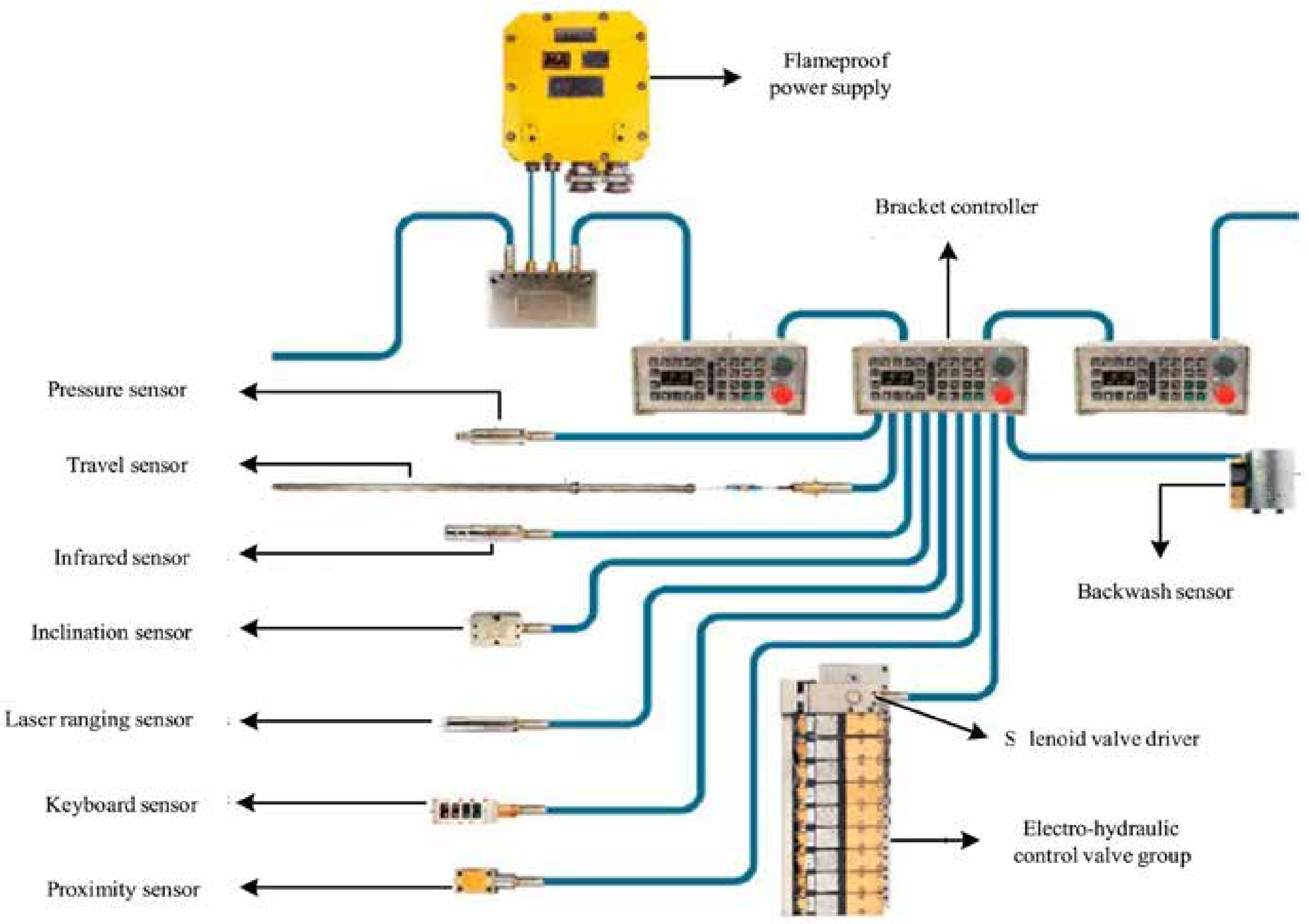

Figure 3: Structure Schematic Diagram of SAC Electro-hydraulic Control System for Hydraulic Support.

hardware (connector and isolation coupler, etc.) and corresponding software for data communication and control function for controller interconnection. A special controller, called a signal converter, is installed, and connected in the No. 2 support of 16,108 intelligent fully mechanised coal mining faces, which can provide more abundant and perfect services for the controller system of the working face.

3. The underground main control computer is set up in the air inlet lane of the 16,108 intelligent fully mechanised coal mining faces and connected with the support controller of the working face through the network through the signal converter to become the upper-level control machine. The main control computer runs its own software, collects, and stores the data and parameters collected and transmitted from the support controller of the working face, calls, and displays these data parameters at any time, and monitors the working conditions and action states of the support.

The SAC electro-hydraulic control system of the hydraulic support can complete various action functions of the support, and the support can realise automatic control in groups, including automatic support moving, automatic push-slip, automatic pull-back slip, automatic extension and retraction of the protective plate, automatic extension and retraction of the telescopic beam, automatic spraying, and so on. The main purpose of the SAC electro-hydraulic control system of the hydraulic support is to realise the function of automatically following the machine and moving the frame with the shearer. When the shearer runs from the tail to the head to clear the floating coal to the No. 80 support, it triggers the push-slip of the No. 43~50 supports, which forms a serpentine oblique cutting feed section, and the No. 1~42 supports carry out full-stroke push-slip, from the No. 1~42 supports in sequence. When the shearer runs from the head to the tail to the No. 20 support, it triggers the push and storage action of the No. 51~No. 100 supports. After the shearer, the No. 6 support lagging behind the shearer begins to pull the support, which is completed in turn.

Automatic Coal Cutting and Video Monitoring System of Shearer

The automatic coal cutting of shearer and the operation of the video monitoring system in 16,108 intelligent fully mechanised coal mining faces are shown in **Figure 4**. The automatic coal cutting system of the shearer adopts a memory cutting TDECS system which is suitable for the coal mining technology of working faces. Firstly, the automatic coal cutting state table is edited, and twenty-two states are edited altogether. The setting process is automation → status table → editing status; Automation → Basic Settings → State Based, traction automation and lateral inclination compensation are set to “start;” Parameters → driver settings → starting the motor “left wireless controller”; the F1 + Auto key can enable the left remote controller to

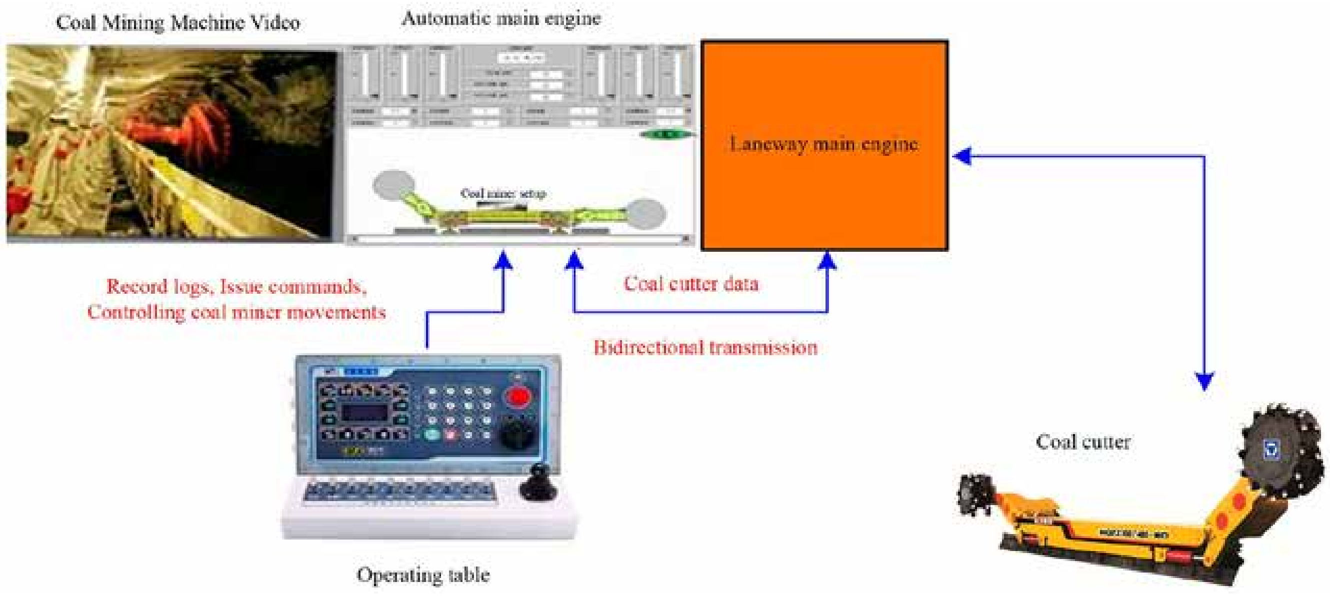

Figure 4: Schematic diagram of automatic coal cutting and video monitoring system of shearer.

control the automatic coal cutting of the shearer, and the shearer driver can properly intervene and fine-tune the coal cutting state of the shearer, including the coal cutting height and coal cutting speed.

At the same time, to ensure real-time dynamic grasp of the working face, one camera is installed on every three hydraulic supports in the working face, which is installed on the front main top beam of the front column. There are thirty-four cameras installed in the working face, seventeen of which face the working face and seventeen face the coal wall. These thirty-four cameras can be automatically switched according to the position of the shearer to ensure that the coal cutting environment of the shearer is always under monitoring. In addition, the 16,108 intelligent fully mechanised coal mining faces are also equipped with cameras in special areas, including the front slipper, rear slipper, transfer machine, front beam detection of the No. 2 support, and train centralised control center, etc. These special area cameras can dynamically monitor the operation and coal flow of these key parts in real time. Three video monitors are installed in the centralised train control center and the ground dispatching sub-control center of the transportation lane of the 16,108 intelligent fully mechanised coal mining faces, 1 of which displays the video of special area fixedly, 1 of which displays the video of working face facing coal wall, and 1 of which displays the video of working face sliding forward.

Intelligent Integrated Liquid Supply System

The intelligent integrated liquid supply system adopts an SAP intelligent integrated liquid supply system, which consists of four parts: a pumping station, liquid tank, control system, and multi-stage filtration system. It is automatic equipment integrating a pumping station, electromagnetic unloading automatic control, PLC intelligent control, frequency conversion control, multi-stage filtration, emulsion automatic proportioning, system running state recording, and uploading, and is a complete liquid supply system for fully mechanised coal mining faces. According to the actual needs of the working face, a liquid supply system with different flow levels and different configuration requirements can be designed, and it is compatible with most pumping stations, combined switches, and frequency converters.

The system is equipped with a multi-stage filtration system, including an inlet water filtration station, water addition filter, high-pressure filtration station, and return liquid filtration station. Through the combination of filter elements with different precisions and flows, the cleaning of the hydraulic medium and the stability of the system are ensured. At the same time, the automatic emulsion proportioning device is adopted in the working face to realise stable automatic emulsion proportioning. In addition, the emulsion pump station adopts electromagnetic unloading control to realise the no-load start and stop of the emulsion pump, and has a variety of intelligent control modes such as single control, upper control, and joint control, which realise the intelligent linkage of multiple pump stations and can realise the intelligent start and stop control of “secondary and standby” pumps according to the liquid consumption situation of the working face. The intelligent control system can automatically detect, display, and control the whole system in real time.

Remote Centralised Control System

Ethernet and intelligent remote-control systems are integrated into the 16,108 intelligent fully mechanised coal mining faces of Binhu Coal Mine to realise the remote centralised control of a ground and transportation lane monitoring center. In the centralised control center, various data of the shearer, hydraulic support, scraper conveyor, transfer machine, crusher, emulsion pump station, spray pump station, and other equipment can be displayed and monitored in real time, and the remote start–stop control of working face equipment can be realised at the same time. A one-button start–stop host screen is shown in **Figure 5**.

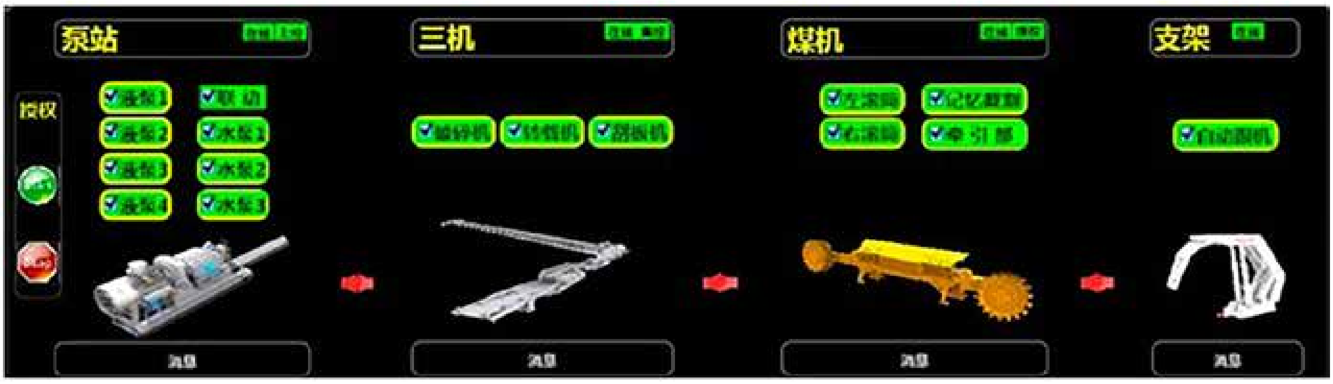

Figure 5: One-button start–stop host screen.

The successful application of a remote centralised control system realises the remote group cooperative control of complete sets of equipment in fully mechanised coal mining faces and provides the real-time production and safety information of underground coal mining faces for ground production and management personnel. The remote centralised control system has powerful functions, simple operation, and reliable operation, which effectively improves the production management efficiency of fully mechanised coal mining faces, improves the safety level of the working face, reduces the labor intensity of workers, improves the production efficiency, and is a favorable guarantee for a high yield and high efficiency of the working face.

APPLICATION EFFECT OF INTELLIGENT MINING IN FULLY MECHANISED COAL MINING FACE OF THIN COAL SEAM

The mining of 16,108 intelligent fully mechanised coal mining faces in Binhu Coal Mine has realised the intelligent cooperative control of complete sets of equipment in fully mechanised coal mining faces. It includes key technologies such as automatic coal cutting by a shearer (automatic coal cutting by a shearer includes oblique cutting feed, triangular coal cutting, bottom coal sweeping, and the upper or lower tail of the whole cutter, etc.), automatic support following (including following machine moving support, pushing and sliding, pulling and sliding, and automatic fluid replenishment of support, etc.), and remote centraliSed control of working face equipment. Compared with ordinary working faces, 16,108 intelligent fully mechanised working faces have obvious advantages in terms of equipment maintenance, equipment operation mode, and working face efficiency.

Maintenance of Intelligent Mining Equipment

The equipment maintenance mode of a traditional working face and intelligent fully mechanised working face is shown in **Figure 6**. The traditional equipment maintenance and repair requires the repair man to go into the working face to check each support one by one, record the support found to have problems, and prepare accessories to enter again for maintenance after leaving the working face as well. Moreover, through the comparison in **Figure 6**, it can be seen that the equipment maintenance under the intelligent mining system only needs the repairman to know the faulty support on the ground, which eliminates the process of entering the working face to check the support one by one, greatly shortens the labor time, improves the work efficiency, and ensures the safety of employees. At the same time, in the mining process of 16,108 intelligent fully mechanised coal mining faces, a clear water filtering device and softened water device are added, and automatic proportioning and emulsion filtering devices are added at the same time. The whole working face requires a high-water quality, so it plays a particularly good role in protecting equipment maintenance.

Operation Mode of Intelligent Mining Equipment

The operation mode of traditional working face equipment is that traditional support control adopts temporary support operation, and the shearer uses a remote controller to follow the machine. People move back and forth in the working face and squat repeatedly, which is not only labor intensive and takes a long time, but also occupies more people and has a low efficiency. The equipment operation

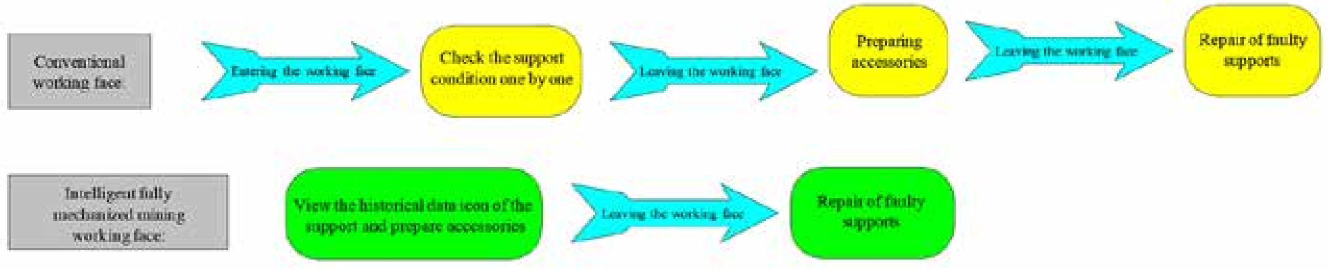

Figure 6: Equipment Maintenance Mode Control Chart.

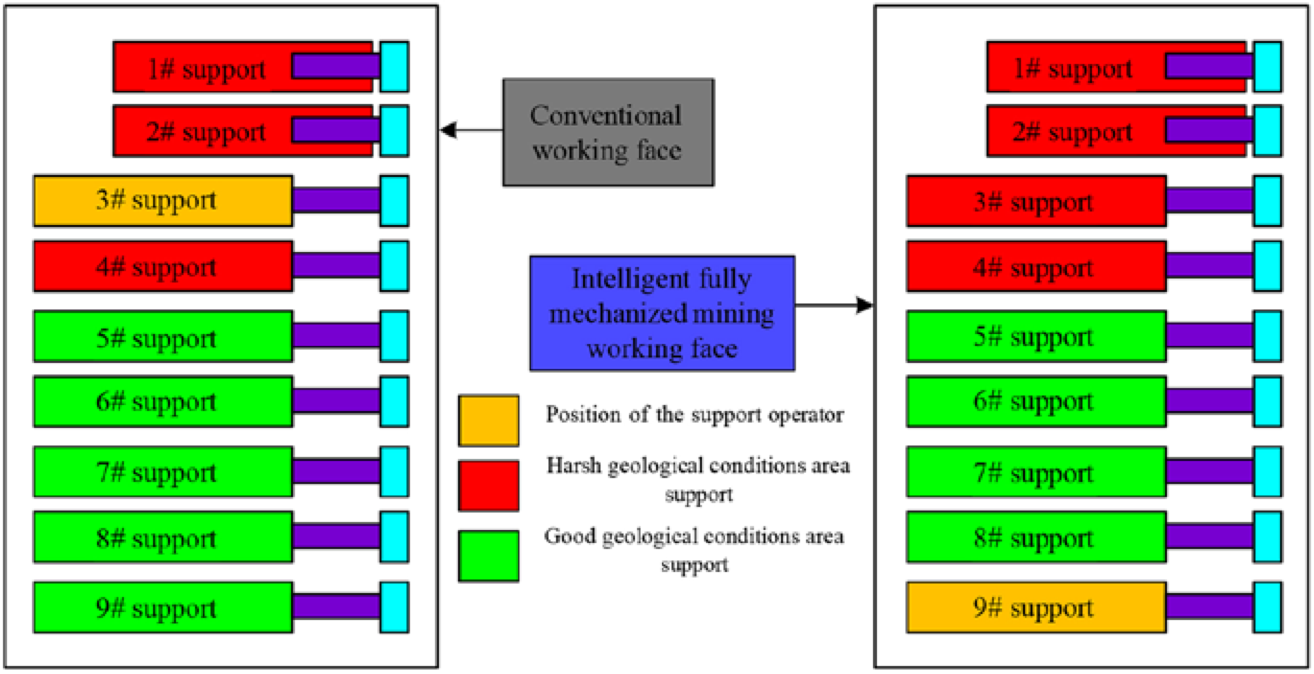

Figure 7: Control diagram of bracket operation mode.

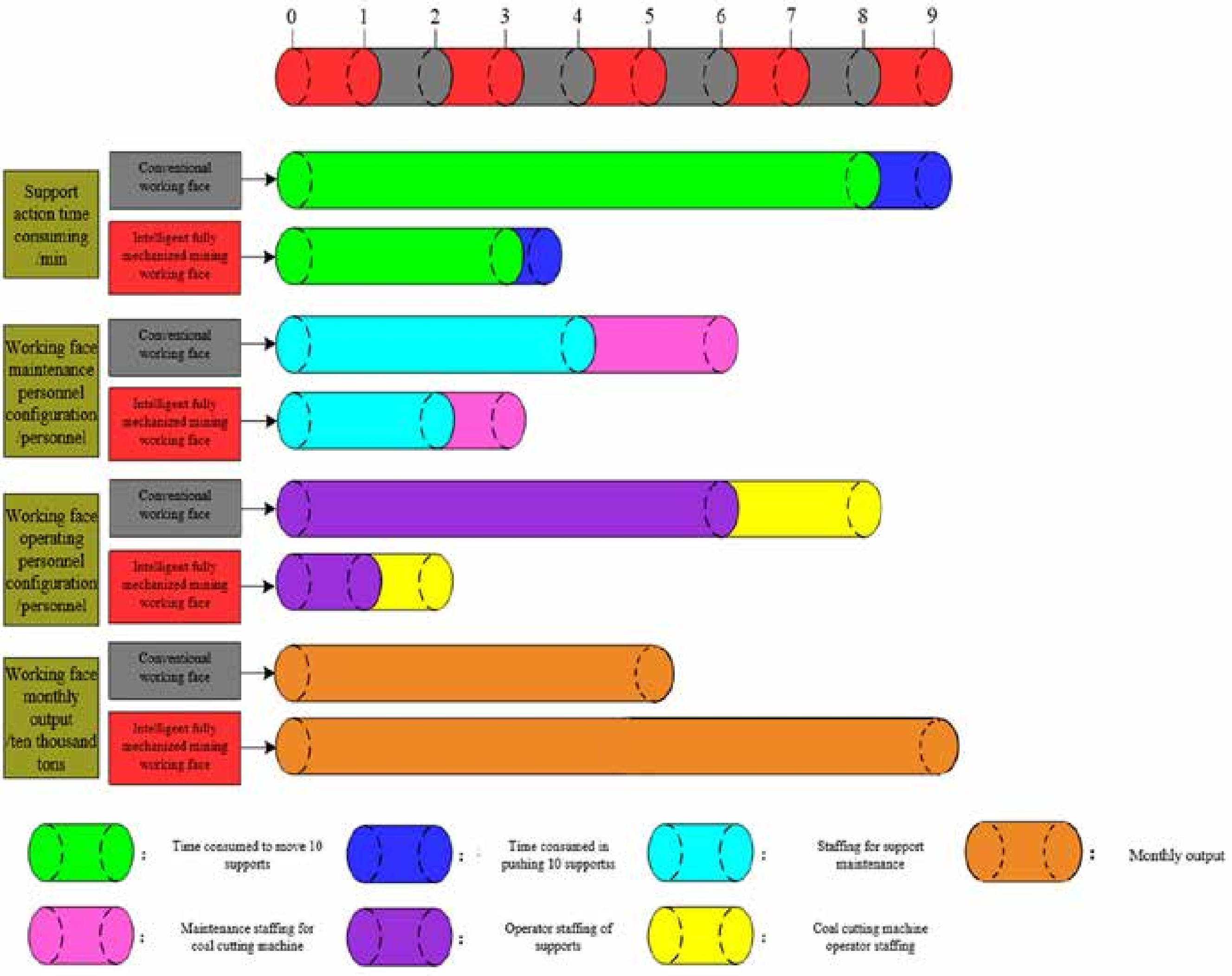

Figure 8: Comparison of working face efficiency.

mode of an intelligent fully mechanised coal mining face is to use the intelligent mining system of a fully mechanised coal mining face in thin coal seam to organise production according to the principle of “unmanned equipment operation and patrolled working face”, that is to say, the working face is equipped with shearer memory cutting and support automatic following (including automatic following and moving support and automatic group pushing and sliding), and the working face personnel correct the engineering quality. It fundamentally avoids the disadvantages of traditional equipment, improves efficiency, and reduces staffing. At the same time, for the support, in the face of harsh geological conditions, as shown in **Figure 7**, the operators of the traditional working face need to work in the cracks of dangerous support, and the safety of employees cannot be guaranteed, while the operators of the intelligent fully mechaniSed working face only need to complete their work outside the dangerous support area, which greatly improves the safety of employees.

Efficiency of Intelligent Fully Mechanised Coal Mining Face

The efficiency comparison between traditional working faces and intelligent fully mechanised working faces is shown in **Figure 8**. It takes 8 min for the traditional working face bracket to move 10 brackets and 1 min to push and slip 10 brackets; however, it takes only 3 min to move 10 supports in an intelligent fully mechanised coal mining face, while it takes only 10 s to push and slip, and the efficiency is 2.8 times that of traditional supports. The time for moving the frame at one time is reduced from 90 min to 32 min. Compared to the traditional working face, the time for moving the frame at one time is reduced by 64.8%. The number of equipment maintenance personnel in the working face is reduced from six to three in the traditional working face, and the number of equipment operators in the working face is reduced from eight to two in the traditional working face, with remarkable results in reducing personnel and improving efficiency. Compared to the traditional working face, the number of underground workers in the intelligent fully mechanised working face is only five, which is 35.7% that of the traditional working face, reducing the number of underground workers. The monthly output of 16,108 intelligent fully mechanised coal mining faces is 90,000 tons, which is 1.8 times that of traditional coal mining faces. By comparing the adjacent traditional working faces of the mine, there are four cycles every day with a footage of 0.7 m, and the 16,108 intelligent fully mechanised working faces increases to seven cycles every day with a footage of 0.7 m. The shutdown time for moving racks is reduced from 360 min to 224 min per day, the net machine time for coal mining is increased from 480 min to 840 min, and the advancing speed of the working face increases by more than 75%.

CONCLUSIONS AND RECOMMENDATIONS

1. Based on the actual situation of 16,108 working faces in Binhu Coal Mine, the intelligent mining support equipment of a fully mechanised working face in thin coal seam is determined, which is composed of a shearer, scraper conveyor, bridge conveyor, and electro-hydraulic control hydraulic support.
2. Based on the reasonable selection of supporting equipment, an intelligent mining system for a fully mechanised coal mining face in thin coal seam is formed,
3. Including an electro-hydraulic control system of hydraulic support, automatic coal cutting, and the video monitoring system of a shearer, intelligent integrated liquid supply system, and remote centralised control system. The automatic coal cutting of the shearer, automatic follow-up of the support, and the remote centralised control of the working face equipment are realised. The successful mining of this working face proves the feasibility of the remote group cooperative control technology of complete sets of equipment in fully mechanised coal mining faces in thin coal seam and accumulates experience for the intelligent mining of fully mechanised coal mining faces in thin coal seam.
4. Compared to the traditional working face, the number of people required under- ground in the intelligent fully mechanised working face is only five, which is 35.7% of the traditional working face; compared to the traditional working face, the time for single frame moving is reduced by 64.8%, the output is 1.8 times that of the traditional working face, and the advancing speed of the working face is increased by more than 75%.
5. Compared to the adjacent traditional fully mechanised coal mining face, 16,108
6. intelligent fully mechanised coal mining faces have great advantages in equipment maintenance, equipment operation mode, and working face efficiency. The successful implementation of this project improves the equipment and technical mining level of thin coal seam and has a significant and far-reaching impact on the development of thin coal seam mining technology in China.

Further references can sought via the following link: https://www.semanticscholar.org/paper/Research-on-an-Intelligent-Mining-Complete-System-a-Ren-Ding/56fa41a81160cd55ddf7576fbf0c6fbdeb581c26

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Conveyor Fires: causes and prevention

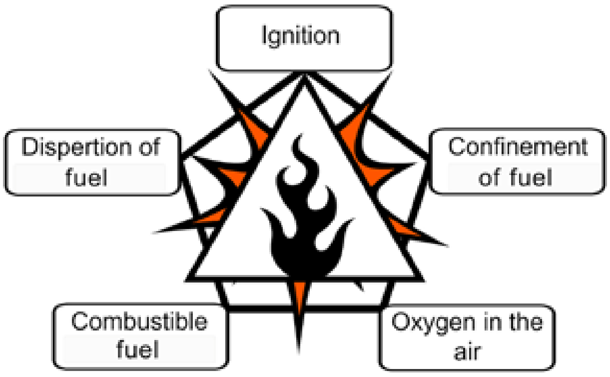
The global leader in conveyor accessories, Martin Engineering, is dedicated to conveyor safety by educating the bulk handling industry on the hazards of conveyor fires. With the Foundations™ Learning Center, the largest comprehensive free conveyor training archive on the web, Martin experts give detailed insight into the causes and prevention of deadly fires. This article, written in collaboration with the authors of Foundations™ for Conveyor Safety, gives an overview of how to improve workplace safety.

CAUSES OF BELT FIRES

To create a fire there must be three elements: oxygen, heat and fuel (aka, "the fire triangle"). One factor that makes conveyor fires so hazardous is that the belt itself can be the fuel. According to a study of belt fires conducted by National Institute for Occupational Safety and Health (NIOSH)[1], any of the standard neoprene, PVC, chloroprene and BELT-approved SBR belts can ignite. Although some belts were self-extinguishing, the conclusion is that *there is no non-flammable belt*, particularly when accompanied by a combustible material[2].

FRICTION

Inadequate belt cleaning in the discharge zone can lead to dust and carryback on the return side of the belt, causing a fouled tail pulley to run under a stalled belt, which creates tremendous heat.



Dust Explosion Pentagon
OSHA https://www.osha.gov/dts/shib/shib073105.html

Dust emissions of any kind (combustible or noncombustible) originating from the loading or discharge zones have a tendency to foul rolling components, leading to failure

Possible Ignition Sources		
Friction	**Dust / Material / Chemical**	**Mechanical / Maintenance**
• Frictional heating of belts riding on non-rotating components • Heat from brake friction • Belt rubbing on structure	• Combustible dust • Out of control high-temperature processes where bulk material temperature exceeds belt capability	• Slip of a belt on a pulley • Cutting and Welding • Mistracking
• Bearing seal failure leading to seized bearings	• Spillage of combustible bulk materials • Accumulations of bulk materials that can spontaneously ignite	• Excessive temperature of the drive • Hot surfaces
	• Flammable liquids	• Sparks and electrical causes

of the seals and then contamination in the bearings and eventually causing the roller to seize. A rolling component can also stall if impact or cargo weight causes the bearings to collapse. Continuous frictional contact with a seized idler or the roller face can cause a loaded belt to exceed safe operational temperatures. It can also potentially result in extreme wear on the belt, degrading the main fire-retardant layer and exposing the heat-sensitive materials found in the belt's inner construction.

CONTROLLING FUGITIVE MATERIAL

Fugitive material control and regular cleaning of spillage are imperative. Without proper belt cleaning, chute sealing and belt tracking, spillage that collects around the loading/discharge areas and along the belt path can damage moving components, restrict access by fire crews and potentially act as fuel.

Dust control is extremely important when handling combustible substances, and it is recommended – instead of just taking into account the fire triangle – operators consider the "Dust Explosion Pentagon." Examples of highly combustible materials include:

- ***Coal*** – Carbon-based, highly flammable material that burns at high heat, with dust that is easily ignited by a spark.

- ***Petroleum coke (petcoke)*** – Carbon-rich derivative of oil processing, used as a coal alternative for power generation, among other applications. In dense concentrations, the dust is combustible with a high-energy spark.

- ***Cellulose*** – A naturally occurring polymer found in wood, paper and grains; dust readily ignites.

Significant amounts of dust can collect on the walls of the loading zone chute. If a foreign metal object is accidentally introduced into the enclosed area, a spark can potentially create an explosion. Additionally, common maintenance within the chute such as removal of the wear liner using a cutting torch often requires confined space entry by workers. If the inside of the chute is not adequately cleaned, this task could pose a serious hazard.

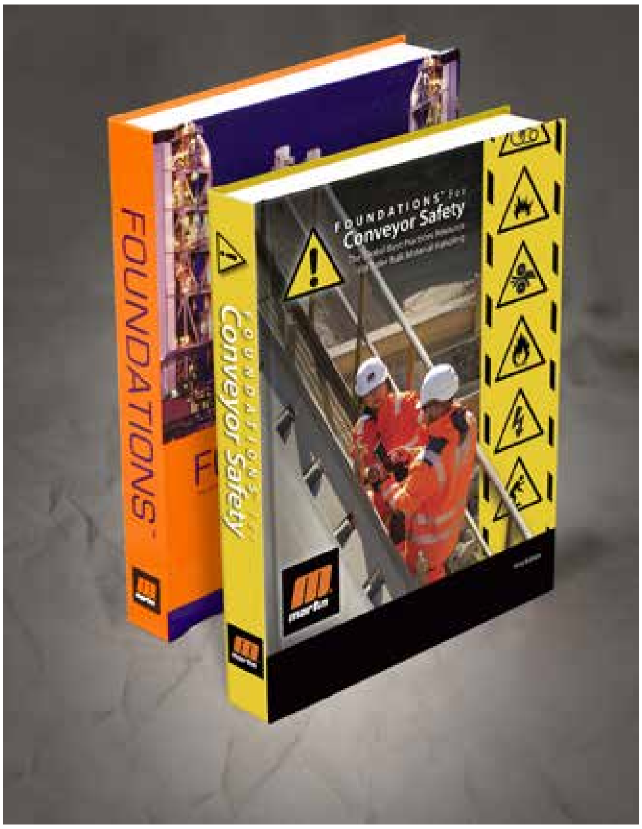
THINK LIKE AN INSPECTOR

When examining conveyor equipment, one should approach the task with the same critical mindset as an inspector from OSHA, MSHA or the local fire department. Safety professionals recommend a holistic view of the system and the combustibility of the material. When making a conveyor fire risk assessment, also consider:

- Spillage levels and cleaning schedules.
- The conveyor's proximity to workstations.
- How the conveyor design (enclosures, narrow walkways, etc.) could create a hazard for employees.
- Safe storage of flammable liquids.
- Compliant signage.

CONSIDERATIONS FOR CONVEYOR FIRE PREVENTION

Often, the potential return on investment (ROI) for prevention equipment isn't recognized until managers are inspecting burnt rubble and negotiating with insurance adjusters. However, safety-minded operators understand that the



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Friction heat between rolling components can be extreme enough to light both the material and belt.

same equipment they would implement for increased efficiency such as belt cleaners and impact cradles, can also help prevent fires.

- *Impact cradles and support cradles* help reduce fugitive material by providing a flat, stable belt surface that facilitates effective sealing.
- *Transfer chute* design is a critical element of fugitive material control, with sufficient settling zones and confinement. New raised chute designs also allow for *external wear liners* that eliminate the need for confined space entry or torch removal. When paired with improved *skirt* seal designs, fugitive spillage and dust emissions are drastically reduced.
- Modern *belt trackers* detect mis-tracking and correct the belt path immediately using troughed idlers or gripping return idlers.
- A heavy-duty *belt cleaner* system featuring modern primary and secondary cleaners with an effective tensioner increases the volume of discharge and limits the amount of carryback and fugitive dust. Along with limiting spillage, tail pulley health is improved and there is less fouling of rolling components.

CONCLUSION

Operators should regularly contain airborne dust at transfer points and remove accumulation. Damaged rollers must be replaced promptly. Conveyor belt alignment is also an essential prerequisite to belt safety. Consider using flame-resistant grease and other lubricants. Fire detection and suppression systems must be tested in accordance to regulatory standards. Experience has shown that clean conveyor systems and ongoing maintenance form the best defense against fire.

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The coal market update

Coal markets are stabilising following recent years of uncertainty unleashed by the global energy crisis. Coal remains the primary global energy source for electricity generation, and increased demand for electricity continues to fuel global coal demand. Clean energy technologies such as solar, wind and hydropower are gaining traction but what impact have recent world events had on their uptake, and are we yet at the point of a structural decline in coal demand?

This Coal Market Update, which provides the latest analysis of coal demand, production, trade and prices, finds that coal demand, supply and trade volumes reached an all-time high in 2023, confirming previous forecasts. It also provides preliminary estimates for the first half of 2024 and outlooks for the full year 2024 and towards 2025, based on recent trends, data and forecasts for economic growth across regions.

Coal continues to be the largest source of carbon dioxide (CO2) emissions and, while carbon capture, utilisation and storage technologies can help reduce coal-related CO2 emissions, the ongoing use of coal has major implications for efforts to reach international energy and climate goals.

GLOBAL COAL DEMAND IN 2023 GREW BY 2.6% TO REACH AN ALL-TIME HIGH

Driven mainly by strong growth in the People’s Republic of China and Hong Kong (hereafter, “China”) of 6%, or 276 million tonnes (Mt), and in India (9.2% or 105 Mt), global coal demand grew by 2.6% in 2023, to reach a new record of 8.7 billion tonnes. The increases in China and India more than offset significant declines in the European Union (-22.5% or -103 Mt) and the United States (-17.3% or -81 Mt)

Coal consumption grew in both electricity generation and industrial sectors, where the iron and steel industry is the largest consumer. Power generation from coal increased by 1.9% in 2023 to 10 690 terawatt-hours (TWh), setting a new record. As a result, coal continues to be the largest source of global electricity generation globally.

IN 2024, GLOBAL COAL DEMAND IS EXPECTED TO STAY BROADLY FLAT

A recovery in hydropower in China combined with significant expansion of wind and solar is expected to slow the growth of coal power generation globally in 2024, albeit with contrasting trends across different regions. Since April, hydropower production in China has rebounded, but electricity consumption in China has grown strongly due to robust increases in demand both in the services sector and industry. At the same time, coal-intensive heavy industries in China (i.e. cement and steel) continue to struggle due to the sluggish real estate sector.

Coal demand increased in both India and Viet Nam in the first half of 2024 due to strong electricity demand and low hydropower output. Meanwhile, India’s economy is growing rapidly, pushing up industrial coal consumption. However,

India’s coal demand growth is expected to slow in the second half of 2024, as the unusually strong increase in demand in the first half of the year was driven by exceptional weather conditions.

In the United States, where coal use has been in decline since 2008, coal demand remained almost unchanged year-on-year in the first half of 2024 due to lower switching from coal to natural gas in the electricity sector. In the European Union, after a 22% decline in coal demand in 2023, we expect a decrease of 19% in 2024, mostly driven by the electricity sector, where the expansion of renewables continues while demand remains relatively weak.

Based on our current assumptions, we expect global coal demand to remain broadly flat for the full year. However, weather, economic activity, natural gas prices and other factors could still result in slight fluctuations. This is particularly true for China’s electricity, sector which accounts for one-third of global coal demand.

In 2025, global coal demand is forecast remain on a plateau The electricity sector accounts for two-thirds of global coal demand. In most countries, coal demand in the power sector fluctuates more significantly than in industrial sectors, largely because there are fewer substitution options for industrial coal use. As such, changes in global coal demand trends are mainly driven by the electricity sector. At the same time, the increasing impacts of unforeseen extreme weather events is making electricity demand harder to predict in the short term.

At a regional level, coal demand in advanced economies is clearly on a downward trend – while in some emerging economies, further growth in demand is very likely. This leaves China as the key variable. Given the most recent data, global coal demand is expected to remain broadly unchanged in 2025 compared with 2024, at around 8.7 billion tonnes.

GLOBAL COAL PRODUCTION REACHED AN ALL-TIME HIGH IN 2023, CLOSE TO 9 BILLION TONNES

In 2023, production by the three largest coal producers, accounting for 70% of global output, grew considerably: China (3.4%), India (12%) and Indonesia (13%). As a result, global coal production reached an all-time high of 8.9 billion tonnes.

China expanded coal production to guarantee energy security and reduce price volatility. In India, energy security is also a high priority, as frequent shortages in the past have turned attention toward reducing imports. Indonesia’s production, despite the increasing domestic need, is export oriented. As such, its production grew in 2023 to meet demand in international markets. In the United States, the fourth largest producer, coal output declined by 2.8%, much less than demand, due to higher exports and stock building. In the Russian Federation (hereafter, ‘Russia’) data show only a slight decline in production, despite exports being subject to sanctions.

PRODUCTION LEVELS IN 2024 ARE EXPECTED TO BE SIMILAR TO 2023

Our analysis for the first half of 2024 shows a slight decline in global coal production of 0.7% year-on-year, driven mostly by China, which recorded a decline of 1.7%. Responsible for half of global coal output, China has intensified safety checks in Shanxi province, the country’s largest producing region, which accounted for 1.3 billion tonnes of coal output in 2023. Pressure to increase domestic production has declined due to slowing demand growth, healthy stocks across the supply chain, and higher imports. India continues to encourage production to avoid coal shortages and reduce imports. Meanwhile, Indonesia aims to produce 720 Mt in 2024, but has mining approvals for more than 900 Mt. Indonesia’s coal production will ultimately depend on international demand, in particular, that of China.

Assuming no new safety inspection programmes, Chinese production is set to recover partially in the second half of 2024 to result in a slight decrease of 0.8%. In India, the strong push to increase production continues and even intensifies. Coal India, the cornerstone of domestic production, is increasing production at growth rates close to 10%. However, production by captive blocks and commercial mines is growing much faster. In Indonesia, we expect little growth after last year's surge.

In the United States, coal production is estimated to have declined 17% in the first half of 2024, partially due to a higher comparison base in 2023 and high stocks in power plants. Despite coal demand in the United States remaining flat in the first half of 2024 rather than decreasing, US coal production is set to continue to decline because of high stocks. In Russia, production is forecast to remain stable in 2024, with domestic demand still robust and exports expected to decline slightly. In Europe, coal production is set to decline. Against this backdrop, our analysis indicates a marginal decrease in global coal production in 2024.

GLOBAL COAL TRADE VOLUMES REACHED AN ALL-TIME HIGH IN 2023

The decrease of around 50 Mt in two key importing areas, Europe and Northeast Asia (Japan, Korea and Chinese Taipei) was more than offset by growth in India, Southeast Asia and China in 2023. Chinese imports reached unprecedented levels of 480 Mt, surpassing the former record by 140 Mt or 40%. This was due to strong demand, stock building, and lower prices than in 2021-2022, which made imports more attractive despite China's boost in domestic coal production since October 2021. This pushed the global international coal trade volume above 2019 highs, surpassing 1.5 billion tonnes for the first time. Seaborne coal trade also reached an all-time high of 1.38 billion tonnes.

All major exporters increased volumes in 2023, except for Russia, due to sanctions. Indonesia became the first exporting country to exceed 500 Mt in a year, demonstrating its unmatched flexibility to ramp up production and exports. Mongolia increased exports to 70 Mt, more than doubling the 2022 figure and more than quadrupling 2021 exports, propelled by improvements in infrastructure and the demand in China for cheap coal.

Trade volumes are expected to reach a new high in 2024
The weak coal demand in Europe and Northeast Asia will result in lower coal imports. Japan, Korea, Chinese Taipei, Germany and other countries in the European Union (EU) are among those in which coal imports, in particular thermal coal, are expected to decline. By contrast, in China, India and Viet Nam, we expect coal imports to increase. The analysis shows trade volumes in 2024 will surpass 2023 volumes marginally and hit a new record. However, this comes with an important caveat, notably the potential for volatile swings in China's import volumes if there are policy changes.

On the supply side, Indonesia, and to a lesser extent, Australia, Colombia and the United States, are expected to supply the additional volumes required to meet others' import demand and offset reduced Russian exports. Mongolian exports to China, mostly coking coal, are expected to grow.

MORE STABILITY IN PRICES AFTER RECENT VOLATILITY

The unusual market conditions of recent years, due to the Covid-19 pandemic, the economic rebound, Russia's invasion of Ukraine, and the subsequent energy crisis, have led to unprecedented energy price fluctuations. The impact on coal was significant, resulting in very high prices and volatility as well as exceptional differences between qualities and geographical regions. Since 2023, coal prices have remained higher than before the Covid-19 pandemic but remain in a normal range. During the last year, thermal coal prices have been less stable than in the 2017-2019 period. Generally, they have been slightly higher, pushed up by cost inflation and some disruption due to sanctions

affecting Russia, which remains the world's third largest coal exporter.

Demand

GLOBAL COAL DEMAND SAW ANOTHER ALL-TIME HIGH IN 2023

In line with our estimates in Coal 2023, global coal demand reached a new record of 8.70 billion tonnes (Bt) in 2023, surpassing the previous year's record by 2.6%. Once again, global coal consumption was led by Asia where more than 80% of coal consumption took place. Conversely, Europe and the United States saw significant declines in coal consumption in 2023.

China, the world's largest producer, importer, and consumer of coal, was recorded with growth in both power (8%) and non-power (2.5%) use of coal. After severe energy shortages and overall weak economic performance in 2022, electricity demand in China rebounded in 2023 growing by 7%. Despite accelerating deployment of wind and solar, most of this growth was met by coal-fired power generation due to low availability of hydroelectric plants, as coal is the main source of flexibility. Together with moderate growth in metallurgical (met) coal consumption and almost flat demand for non-power uses of thermal coal, China's coal consumption increased by 276 Mt, reaching a total of 4 883 Mt in 2023. The overall energy consumption growth rate of coal was slightly lower due to a quality deterioration following a leap in the domestic production of coal.

India has been the second largest source of growth in global coal consumption. Its strong economic performance has propelled power demand, and in turn, demand for coal in power generation (+10%). Unlike in many other parts of the world, in India, growth in renewable energy sources is unable to keep pace with the growth in power demand. Moreover, India's focus on infrastructure has led to more consumption of cement and steel, materials typically produced with coal. As a result, overall coal consumption aggregated to 1 251 Mt in 2023, an increase of 9% compared to the previous year.

Coal consumption in the United States and European Union plunged by 17% and 23% respectively in 2023, representing their most significant annual decline of this century apart from the reduction caused by Covid-19. In the United States, coal consumption decreased because of the retirement of coal plants, decreasing power demand and low gas prices. At the same time, after high coal consumption in 2022, coal demand in Europe returned to a decline, the trend for most of this century.

Beyond that, there were significant regional differences in coal demand. While coal consumption in the ASEAN region mostly increased (+38 Mt), countries like Japan, Korea and Australia saw moderate declines below 10%.

GROWTH IN GLOBAL COAL DEMAND IS EXPECTED TO FLATLINE IN 2024

During the first six months of 2024 we expect global coal consumption to have grown by 1.0% to a total of 4 308 Mt. This is despite consumption of coal being expected to remain unchanged in non-power applications. However, coal consumption in the power sector is expected to have grown by 1.4%. The major contributors to growth within the power sector have been India (+44 Mt) and China (+22 Mt), while the European Union is estimated to exhibit the strongest decline (-2 Mt).

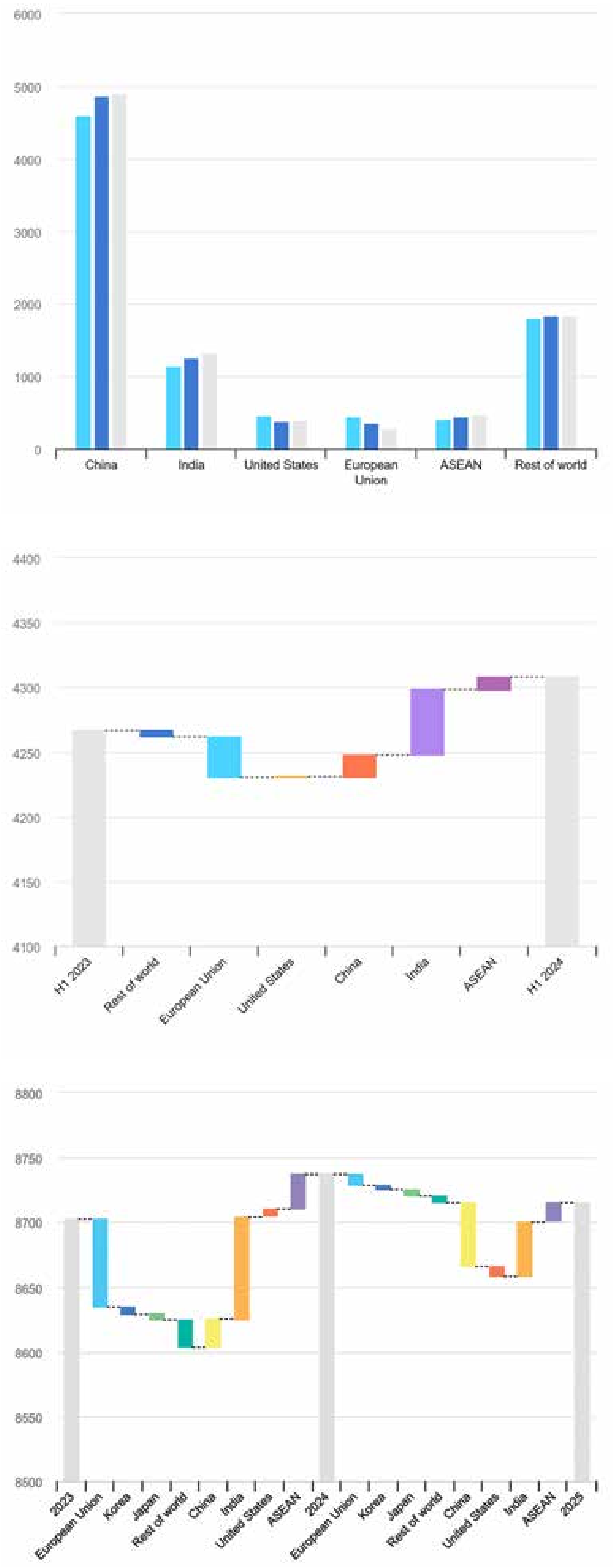
In the second half of 2024, we expect a decline in coal-fired power generation to partially offset gains from the first half, resulting in coal consumption in the power sector of 5 886 Mt for the full year, up 0.5%. Together with stable consumption of coal in non-power applications in the second half of 2024, this would imply a slight increase in global coal consumption. We expect it to reach 8 737 Mt (+0.4%) for the full year 2024.

In our last publication we forecasted coal demand would decrease in 2024 with a moderate decline thereafter. However, this forecast was subject to two important caveats: a recovery of hydropower generation in China after years of low rainfall, and a slowdown in Chinese electricity demand growth. While hydropower has made a strong recovery since April 2024, growth in electricity demand in China has remained robust. In India, the second largest coal consumer, heatwaves and low availability of hydropower in the first half of 2024 have increased the use of coal for power generation and therefore, coal demand. In addition, countries like Viet Nam and the United States have contributed to the adjustment in our forecast for 2024 due to weather incidents and reduced switch to gas.

Following the EU's major drop in coal consumption in 2023, we expect the European Union to show another significant reduction in 2024. After the difficulties of the 2022 energy crisis, and despite the unprecedented rise in gas prices being largely overcome, the European Union continues to show weak industrial activity and stagnating growth in power demand. Here, the rise of renewables combined with improved performance of nuclear is expected to significantly affect coal demand. We estimate the EU's coal demand will shrink by 19% down to 287 Mt, making it the first time in IEA records that the coal demand of EU countries falls below 300 Mt. Conversely, we estimate the United States to show no significant changes in coal consumption in 2024 after last year's big decline. Last year, we forecast a decline, but the growth in power demand is higher than expected and the coal-to-gas switch has reduced.

In China, we estimate that coal-fired power generation increased about 1.5% during the first half of 2024. High precipitation starting in April 2024 increased the availability of hydroelectric power. Given the accelerating deployment of renewables, particularly solar PV, we estimate Chinese coal demand in the power sector will grow by 0.9% in 2024. This would be the lowest growth rate since 2015. However, there is significant uncertainty concerning the availability of hydropower and the growth in power demand, which are key determinants for coal demand in China. Coal is used for many different applications beyond the power sector in China. The iron and steel industry, consuming mostly met coal, is the largest non-power consumer.

Global coal consumption, 2022-2024



Production of building materials (mainly cement) and chemicals (mostly through coal gasification) are the main consumers of thermal coal. Overall, we expect non-power demand to remain flat amid declining use in the building sector owing to a dragging real estate market, whereas consumption of coal used for coal gasification is expected to increase.

In India, for the first half of 2024 we estimate the consumption of thermal coal for power generation to have increased almost 10% and met coal consumption in India to have increased by just over 2%. Heat waves have escalated electricity demand while hydropower output has been very low. With this trend likely to decline during the second half of the year, we estimate a coal demand of 1 330 Mt in 2024, up 6% compared to 2023. Weak performance of hydropower and strong growth in power demand are also causing significant growth in coal demand in Viet Nam during 2024 (+12%).

COAL DEMAND IS ESTIMATED TO DECLINE MARGINALLY IN 2025

In 2025, we estimate global coal demand to enter a trend reversal after four years of growth, decreasing slightly by 0.3% to a total of 8 714 Mt. A key reason for this is that China, which has traditionally driven coal demand growth, is likely to show its first decline in coal demand since 2016. This combined with ongoing declines in the European Union, United States, Japan, Korea, and other parts of the world, is expected to outweigh continuous growth in India and ASEAN.

Global coal consumption is highly driven by developments in the power sector, which currently accounts for more than two-thirds of global coal use. Within the power sector, coal demand is highly affected by weather. Fluctuations in weather conditions influence both the supply and demand side, particularly relating to the growing capacities of weather-dependent renewable energy sources and ongoing electrification. Additionally, fundamental drivers, such as the production of clean energy technologies like electric vehicles or global trends like AI propelling demand from data centres, will have a significant impact on electricity demand, and in turn, coal demand in the coming years. Indeed, policies to phase out coal and reduced support for coal from institutions like banks or insurers in many parts of the world are going to put further pressure on coal demand. Regionally, the expected decline in coal demand in developed economies and the growth in some emerging countries seems certain, leaving China as the largest source of uncertainty, potentially deciding the global trend for coal demand.

For 2025, we estimate Chinese coal demand in the power sector to decline by 1.1%, since renewables are likely to outgrow power demand. However, this forecast comes with caveats regarding electricity demand, hydropower output and solar PV curtailment rates. If there are no remarkable changes in coal demand for non-power applications, China is estimated to show a reduction by 49 Mt in 2025, contributing the most to the reduction in global coal demand. On 15 July, 2024, China issued the Action Plan for Low-Carbon Coal Power Transformation (2024-2027), which supports three key technologies to reduce CO2 emissions from coal plants: biomass, ammonia co-firing and Carbon, Capture, Utilisation and Storage. This Plan will affect coal consumption in China from 2025 onwards, but it is too early to make a detailed assessment of the impact, so it is not included in this report.

Further reductions in coal demand are estimated to occur in the United States (-8 Mt or -2.0%) and in the European Union (-9 Mt or -3.0%) given the region's ongoing efforts to phase out coal.

In India, the rise of renewables will likely not cover the growth in power demand. Therefore, we expect coal plants to capture part of the growth. Given India's rising demand for coal in industrial applications, we estimate aggregate coal demand to increase by 3.1% to 1 371 Mt in 2025. In 2024, India aims to commission 14 GW of new coal-fired capacity, more than four times the annual average in the last five years. Likewise, coal demand in ASEAN is estimated to grow by 3.0% in 2025.

Supply

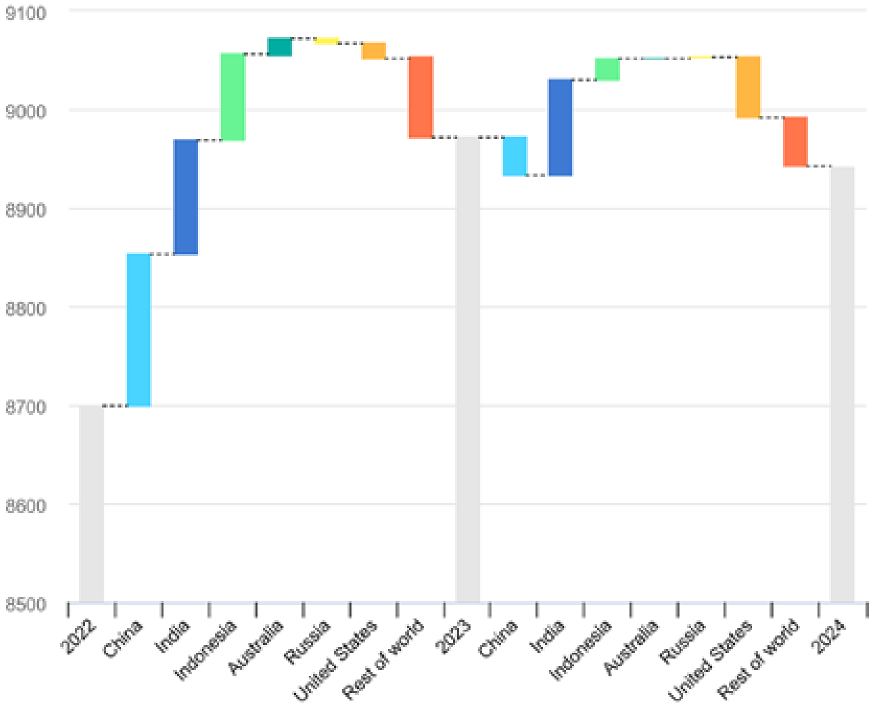
GLOBAL COAL PRODUCTION IN 2023 GREW CLOSE TO 9 BT

Global coal production in 2023 grew by 3.1% to 8 970 Mt, an all-time high, driven by a push from the top three coal producers China, India and Indonesia. Their combined total coal output increased by about 356 Mt, compared to 2022, resulting in a share of 72% of global coal production. At the beginning of this century, this share stood at slightly more than a third of global production, underscoring the substantial shift in global coal production over the last two decades.

After supply shortages in 2021, Chinese officials called for a boost in production, which resulted in a significant increase in 2022, and continuous growth throughout 2023. Nonetheless, the rise in production came with a higher rate of mine accidents and a notable deterioration of quality. Given China's growing coal output and growing import volumes, it has shown a total supply of coal totalling more than 5 Bt, which dramatically exceeds any other country or region.

In Indonesia, production reached 775 Mt, significantly exceeding the production target of close to 700 Mt for 2023. Growth in domestic requirement as well as demand from China and other importers in that region have propelled the surge in Indonesian coal production.

As expected in our previous forecast, India has surpassed the mark of 1 Bt of coal production in 2023, showing a growth of 12% or 116 Mt. In India, recent investment in infrastructure and in mine expansions has supported increased coal production.



In 2023, Australian production grew by about 3.8% to 450 Mt. In Australia, a change in weather pattern from La Niña to El Niño during 2023 improved overall mining conditions, although bushfires and labour shortages diminished the favourable conditions. In the United States, production declined by 2.8% in 2023, as domestic demand slipped amid low gas prices. However, that decline is much lower than demand, owing to higher exports and strong stock building. Likewise, a slight decrease in coal output has been observed in Russia (-1.1%), where sanctions are affecting exports.

GLOBAL COAL PRODUCTION IS EXPECTED TO FLATTEN IN 2024

We expect global coal production in 2024 to decrease very slightly by 0.3% to 8 939 Mt. At a regional level, we expect growth in India and Indonesia, which are overcompensated by declines in China and in the United States.

In China, security issues in mining in the Shanxi region and subsequent stricter security checks reduced the production of coal in the first half of 2024. Shanxi is the largest coal producing region in China, surpassing 1.3Bt, and therefore, producing more than any country. However, we expect the decrease of 1.7% in the first six months to be moderated in the second half, as security checks are relaxed. For the full year of 2024, we expect a moderate decrease of 38 Mt to a total of 4 572 Mt in Chinese coal production. June 2024 already recorded a year-on-year increase of 3.6%. Given an anticipated slowdown in Chinese coal demand growth in the second half of 2024, we note that a recovery in production will have implications for imports and already ample stocks.

In Indonesia, we expect coal production to show slight growth during 2024. Indonesia's Ministry of Energy and Mineral Resources has raised the coal production quota for 2024, also known as RKAB, by nearly 30% to 922 Mt. However, this number assumes operation at full capacity and typically producers reach usage of around 80%. Despite heavy rains in Sumatra and South Kalimantan in the first quarter of 2024, coal production in the first four months of 2024 has already gained 8.6%. In addition, domestic demand for coal is expected to increase, fuelled by electricity, the nickel industry and others. Nonetheless, close to 30% of Indonesian production is consumed in China, whose demand is estimated will flatten for the rest of the year. Against this background, we estimate a production of around 800 Mt in Indonesia for the full year 2024, growing by 2.9%.

In the United States, coal production in the first six months of 2024 was down 17% compared to the first half of 2023. Despite a slight increase in demand in 2024, coal production is expected to decrease by 12% down to 463 Mt in 2024, due to strong stock building in US power plants in 2023.

Aggregate coal production in Russia shows no sign of significant change in 2024. Nonetheless, there is some shift between producers within Russia. For example, Elga showed a growth of 31% during the first five months in 2024 to more than 10 Mt, but Russia's biggest producer Suek, currently under US sanctions, records a reduction of 4%. It is worth noticing that Elga was included in the US sanction list in June 2024, so it is yet to be seen how this impacts its production.

India continues to push coal production, as highlighted by a growth of almost 10% in the first half of 2024, with June exhibiting an outstanding growth of more than 14% compared to the same period in 2023. Given India's intensified efforts to overcome energy shortages and, at the same time, reduce import quantities, we expect its production to gain 9% for the full year. Thus, India is expected to contribute the most to global coal production growth, under the assumption that China will not trigger its production in the second half.

Coal production in Australia showed no significant variation in the first quarter of 2024 compared to the first quarter of 2023. In June 2024, an underground fire in the Grosvenor mine reduced the production of met coal, however, we do not expect this to significantly affect Australia's annual output. Thus, we expect Australian production to remain flat in 2024 at about 450 Mt.

All text and data taken from, please use the following link for a more detailed report: Supply – Coal Mid-Year Update – July 2024 – Analysis - IEA

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