

Application of Intelligent Safety Technologies in Aluminium Electrolysis

Yaorui Li

Onsite-Manager

Guangxi Hualei New Materials, Pingguo, China

Corresponding author: 490122260@qq.com

<https://doi.org/10.71659/icsoba2025-al072>

Abstract

The domestic work safety situation is severe, particularly in high-risk industries like aluminium electrolysis, where safety management faces significant challenges. To enhance safety performance, investment and application of intelligent safety technologies are urgently needed. The introduction of intelligent safety technologies like 5G and IoT facilitates automation in production and remote maintenance. The use of Virtual Reality (VR) and Augmented Reality (AR) enables intelligent education and training. Using big data technology for risk identification, hazard investigation and governance eliminates repetitive issues and effectively implements the dual prevention mechanism. The use of intelligent platforms has enhanced safety information sharing among workshops and teams in smelters, while also easing supervisory inspections by management departments. The use of intelligent safety technologies has enhanced convenience and real-time capabilities in safety management, making work safety more efficient and precise.

Keywords: Intelligence, Safety technologies, Big data, Intelligent platforms, Efficient and precise.

1. Overview of Work Safety in Aluminium Electrolysis

1.1 The Important Role of Aluminium Electrolysis in the National Economy

Aluminium electrolysis represents a vital foundational industry within the national economy and serves as a key pillar in the pursuit of manufacturing excellence. Aluminium products, characterized by their diverse types, extensive applications, and significant strategic value, constitute an essential sector for ensuring national resource security and industrial security. Since the implementation of "The 13th Five-Year Plan", the production of aluminium in China has greatly increased to beyond the rest of the world since 2013 as shown in Figure 1.

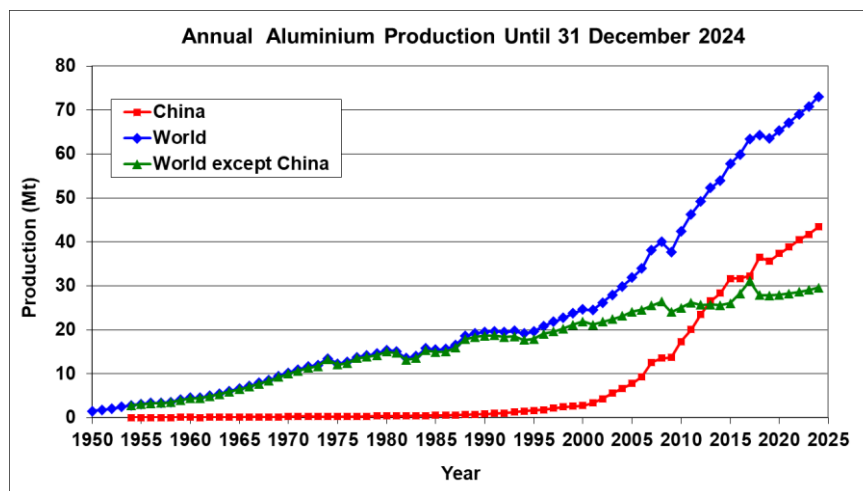


Figure 1. Chinese and World primary aluminium production, IAI statistics [1].

1.2 Existing Risks in Aluminium Electrolysis Production

1.2.1 Major Risks

In the field of aluminium electrolysis, the production process entails the handling of molten metal, which necessitates various methods for transferring or transporting the molten metal between different steps of the process. The occurrence of high-temperature molten metal leakage poses significant risks, potentially leading to burns, fires, or even explosions [2, 3].

Leaks, slag overflow, or splashing during the processes of molten metal smelting and casting can result in explosions when molten metal comes into contact with water. Particularly in the processes of aluminium processing, such as deep pit casting, the leakage of molten aluminium into the casting pit and its subsequent contact with water can lead to explosive reactions. These accidents will result in severe consequences.

Aluminium smelters utilize natural gas across various processes, supported by extensive pipeline networks. In the event of a leakage or flashback, such incidents may result in fires or explosions. Table 1 gives a list of smelter’s major risks.

Table 1. List of smelter’s major risks.

1. Electrolysis process		
Risk Point	No.	1
	Type	Electrolytic cell
	Name	Aluminium tapping operation in electrolytic cell
Step	S/N	3
	Name	Aluminium tapping
Hazard Source or Potential Incident		Abnormal cell voltage during aluminium tapping
Assessment Level		1
Risk Classification		Major Risks
Potential Accident Type and Consequence		Equipment Damage
Control Measures	Engineering Technical Measures	High voltage alarm set by cell control unit
	Management Measures	Strict inspection and assessment
	Training and Education Measures	1. Conduct regular training on technical procedures for safe operations for operators; 2. Carry out regular emergency training
	Personal Protective Measures	Operators must wear safety helmets, face masks, protective clothing, gloves, and safety shoes.
	Emergency Response Measures	1. Immediately stop the aluminium tapping operation; 2. Switch the cell control unit to manual mode and adjust the voltage.
Management Level		Company
Responsible Unit		Company department
Person in Charge		Smelter branch or potroom
Remarks		

1.2.2 High Risks

Molten salt aluminium electrolysis cells contain molten metal or high-temperature raw and auxiliary materials during production. If the inner wall of the electrolytic cell is damaged, it may result in the leakage of high-temperature melts, which could potentially lead to burns and fire hazards.

Adding water-containing raw and auxiliary materials during pyrometallurgical processes can lead to "blasting" of molten metal. This occurrence may result in splattering of molten metal, which poses significant risks such as burns, fires, or even explosions.

If containers that come into contact with molten aluminium (such as ladles, launders, or casting moulds) are not properly dried, are damp, or contain water, this may lead to splashing burns, fires, or explosion incidents.

If molten metal ladles are transported without the use of metallurgical casting cranes or specialized transport vehicles, there is a risk that the ladles may tip over during transit. This could result in leakage of molten metal, potentially leading to burns or fire hazards.

In aluminium processing, particularly in deep pit casting operations, the utilization of wire rope hoists to draw casting bases (pallets) can inadvertently lead to base instability. This instability may result in mould breakout, which poses a significant risk of molten aluminium explosion accidents upon contact with water.

Table 2 present a list of smelter's high risks.

2. Application of Remote Intelligent Safety Technologies [5–7]

2.1 Application of 5G Simulation Model Technology in Work Safety

The application of a 5G simulation model in work safety not only improves the accuracy of monitoring and early warning but also reduces the risk of human errors through intelligent and automated means, providing strong guarantee for the continuous safety of industrial production. With the continuous development of 5G technology and the expansion of its application fields, its potential in work safety will be further advanced.

2.1.1 Real-time Monitoring and Early Warning System

Using the high bandwidth and low latency characteristics of 5G technology, in conjunction with a simulation model, enables real-time monitoring of key parameters in the production environment, such as temperature, pressure, and liquid level. In scenarios such as temperature detection in casting holding furnaces and liquid level monitoring of molten aluminium launders, the system is capable of promptly issuing early warnings upon the detection of abnormalities. This functionality effectively contributes to accident prevention.

The simulation model is capable of simulating potential hazardous scenarios, including equipment faults and electrolytic cell tap-out. This functionality aids in the proactive development of emergency response plans.

2.1.2 Virtual Reality (VR) and Augmented Reality (AR) Training

Through high-definition video streams transmitted via 5G networks and simulation models, immersive VR/AR training environments can be created to simulate virtual scenarios such as

electrolytic cell tap-out, molten aluminium combustion fires, and high-altitude fall accidents. Employees can simulate actual operations in virtual environments, learn how to properly respond to emergencies, and improve safety awareness and operational skills.

Table 2. List of smelter’s high risks.

1. Electrolysis process			
Risk Point	No.	1	2
	Type	Electrolytic cell	
	Name	Aluminium tapping operation in electrolytic cell	
Step	S/N	1	2
	Name	Tool preparation	Ladle lifting and transportation
Hazard Source or Potential Incident		Tools and devices are damp during aluminium tapping.	Molten aluminium in vacuum ladles absorbs excessive aluminium.
Assessment Level		2	2
Risk Classification		High Risks	High Risks
Potential Accident Type and Consequence		Burns and scalds	Burns and scalds
Control Measures	Engineering Technical Measures	Set up workshop signage stating "Tools must be preheated before use".	Set up an overweight alarm for the electronic scale.
	Management Measures	1. Conduct regular training on technical procedures for safe operations for operators; 2. Carry out regular emergency training and drills.	
	Training and Education Measures	Operators must wear safety helmets, protective masks, gloves, and high-temperature-resistant safety shoes.	
	Personal Protective Measures	Operators must wear protective masks, insulating gloves, and insulating shoes.	
	Emergency Response Measures	1.Immediately stop the aluminium tapping operation 2.Provide on-site first aid to the injured and call 120.	
Management Level		Smelter branch	Smelter branch
Responsible Unit		Smelter Manager, Section Manager, Workshop Director, and Team Leader	Smelter Manager, Section Manager, Workshop Director, and Team Leader
Person in Charge		Smelter branch or potroom	Smelter branch or potroom
Remarks			

2.1.3 Remote Monitoring and Maintenance

The 5G simulation model supports remote monitoring of critical equipment, enabling early detection of faults. Enhanced by the extensive connectivity capabilities of 5G technology, it is capable of simultaneously monitoring a substantial number of devices, thereby improving maintenance efficiency.

When necessary, experts can provide remote guidance or operations via 5G networks to quickly resolve on-site issues, reducing production interruptions caused by equipment faults. Figure 2 shows remote monitoring system diagram of a smelter.

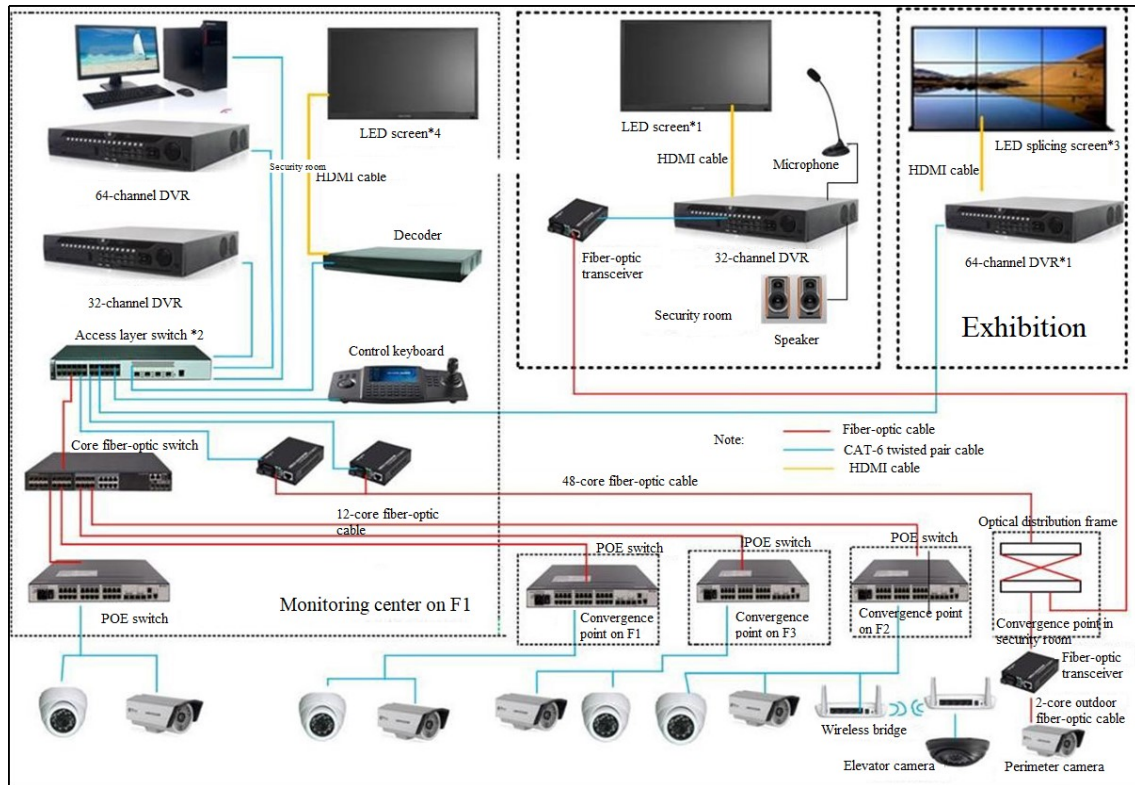


Figure 2. Remote monitoring system diagram of a smelter.

2.1.4 Automated and Intelligent Production

The 5G simulation model is capable of simulating and optimizing production line processes. The introduction of automatic anode replacement simulation models for electrolytic cells, along with aluminium tapping simulation models, enhances the levels of automation in these operations. Through the analysis of real-time data, the system is capable of predicting production bottlenecks, optimizing resource allocation, and minimizing human errors. Consequently, this enhances overall work safety.

2.1.5 Environmental and Health Monitoring

In aluminium electrolysis production environments, 5G simulation models can be used to monitor various environmental factors, including air quality and noise levels. This monitoring ensures that the working conditions for employees adhere to established health standards.

By incorporating health data gathered from wearable devices, simulation models can effectively analyse employees' health conditions and mitigate the risk of occupational diseases.

2.1.6 Intelligent Safety System

By using a 5G simulation model, it is possible to develop an intelligent safety system that incorporates facial recognition and behaviour analysis, thereby enhancing the safety protection capabilities of the smelter.

In emergency situations, the intelligent safety system is capable of swiftly activating emergency response plans, facilitating personnel evacuation, and minimizing casualties.

2.1.7 Data Analysis and Decision Support

The 5G simulation model is capable of processing and analysing substantial volumes of production data, thereby identifying potential safety risks associated with aluminium electrolysis production. This data offers valuable decision-making support for management, facilitating the development of more effective work safety strategies.

2.2 Application of Virtual Reality (VR) and Augmented Reality (AR) in Safety Training

The utilization of Virtual Reality (VR) and Augmented Reality (AR) in safety training is becoming increasingly prevalent. The primary advantage of these technologies lies in their ability to simulate real-world scenarios, thereby facilitating the acquisition of safety skills and enhancing emergency response capabilities among personnel.

2.2.1 Key Application Scenarios

Work safety and process training. VR technology is used to develop 3D simulation scenarios of electrolytic cells, thereby replicating the operational processes of multifunctional cranes, electrolytic cells, casting equipment, etc. This approach aims to assist electrolysis workers in becoming acquainted with the structural components of the equipment and understanding shift handover rules effectively.

Accident simulation and emergency drills. VR technology is used to simulate accident scenarios, including molten aluminium explosions upon contact with water, electrolytic cell leaks, and fires. This approach integrates dual tactile and visual stimulation through the use of vibration platforms and digital gloves, thereby enhancing emergency response capabilities and evacuation skills. Accidents such as falls from heights and electric shocks are simulated to assist employees in mastering appropriate escape postures and emergency response procedures.

Risk prediction and planning optimization. VR technology is used to conduct 3D modelling of electrolytic cell structures and equipment layouts. This approach aids engineers in anticipating potential risks associated with aluminium electrolysis, while also optimizing the design and arrangement of electrolytic cells to enhance both production efficiency and safety.

Accident investigation and retrospective analysis. After an accident, VR technology is used to reconstruct the scene environment, reproduce the accident process, and assist investigators in quickly analysing the cause and proposing improvement measures.

2.2.2 Technical Characteristics

High authenticity and multi-sensory interaction. Multi-dimensional perception, encompassing vision, hearing, and touch, is simulated through the application of 3D modelling technology that utilizes real data. This simulation is further enhanced by integrating hardware components such as stereoscopic helmets and vibration platforms, thereby augmenting the immersive experience of the scene. For instance, the physical impacts associated with equipment faults (such as vibration feedback and visual feedback) are simulated to amplify the training's immersive effects.

Personalized learning paths. VR systems are capable of adapting instructional content and difficulty levels in accordance with the trainees' progress. It can monitor learning behaviours in real time and provide feedback to assist in rectifying erroneous actions.

Cost-effectiveness and flexibility. There is no need to construct physical training sites. The training materials are reused to minimize expenses, without any limitations related to time or space.

2.2.3 Aluminium Electrolysis Application Cases

High-risk scenarios are simulated using VR technology, and dedicated VR simulation training rooms are established to facilitate cost-effective and efficient training.

Virtual chemical factory environments are designed to provide training for employees in effectively responding to fires, leaks, and other types of accidents.

Fire safety education is delivered, and fire scenarios are simulated to instruct individuals on the appropriate use of fire extinguishers and evacuation procedures.

2.2.4 Future Prospects

With the continuous advancement of VR/AR technology, its application scenarios will expand to more processes in aluminium electrolysis, such as simulation of anode replacement, aluminium tapping, and anode beam raising. In the future, the integration of artificial intelligence (AI) technology with VR/AR systems is expected to facilitate more intelligent and personalized training experiences. This advancement will further enhance the effectiveness of safety training.

Through the above applications and technological advantages, VR/AR is becoming an important innovative approach in the field of safety training, helping aluminium smelters reduce accident risks and improve overall safety standards.

3. Application of Big Data Technology in Safety Management

3.1 Advantages of Big Data Technology

3.1.1 Large Capacity

The capacity of big data has now reached petabyte (PB) range, and can even extend to exabyte (EB), zettabyte (ZB), and yottabyte (YB) scales.

3.1.2 Diversity

In the era of big data, it encompasses not only structured data but also unstructured data, including videos, images, emails, and logs.

3.1.3 Fast Speed

In practical applications, the retrieval speed for data at the hundreds of Mb/s must achieve a response time measured in seconds.

3.1.4 Value

Achieving more efficient data value "purification" through advanced machine algorithms continues to pose a significant challenge in the age of big data.

3.2 Application of Big Data Technology in Aluminium Electrolysis Risk and Hazard Management

3.2.1 Data Collection and Integration

Through the acquisition of multi-source data from IoT sensors, mobile devices, and enterprise information systems, we integrate equipment operation data, electrolytic cell temperature monitoring data, and personnel operation records. Utilizing data cleaning and storage technologies, we establish a unified large database that serves as a solid foundation for subsequent analysis.

3.2.2 Aluminium Electrolysis Hazard Identification and Analysis

Exception detection: Data mining algorithms, including association rule mining and time series analysis, are employed to identify abnormal factors in the aluminium electrolysis production process. These factors may include voltage discrepancies and temperature fluctuations, which are assessed to determine whether they pose safety hazards.

Trend prediction: The developmental trends of hazards are analysed using historical data, enabling the prediction of potential accident consequences. This analysis provides a foundation for early intervention.

3.2.3 Risk Assessment and Early Warning

Quantitative assessment: A risk assessment model is developed to quantify the levels of potential hazards and establish governance priorities.

Real-time early warning: Risk level warning thresholds are established. Immediate alarms are activated when monitoring data surpasses these limits, ensuring that relevant personnel are notified to take corrective actions promptly.

3.2.4 Governance Strategy Optimization

Based on the results of risk assessments, scientific and reasonable corrective measures, emergency response plans, and personnel training plans are developed. Governance strategies are continuously optimized through the utilization of big data.

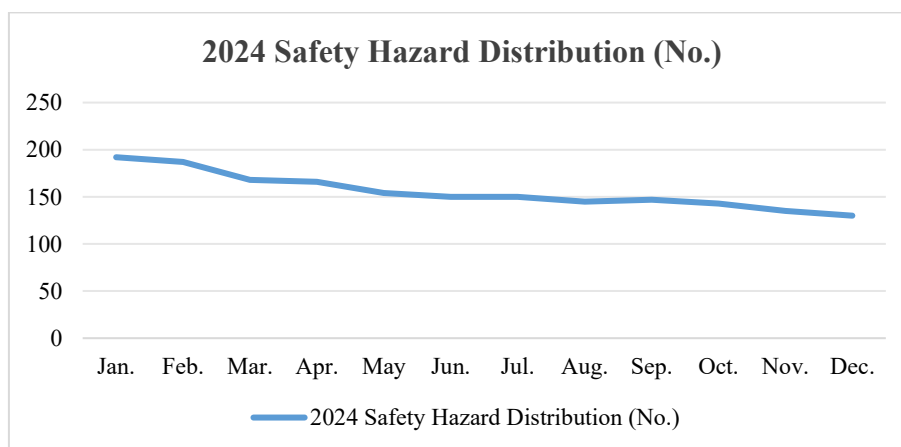


Figure 5. Number of hazards per month after the application of big data in a smelter.

4. Application of the Intelligent Platform in Safety Management

4.1 Efficiency Improvement and Resource Optimization

4.1.1 Automated Processing

The intelligent platform minimizes manual intervention by using automated processes, including automatic test paper generation (completed in just 10 seconds), batch file processing, and the generation of intelligent operation and maintenance reports. This significantly enhances work efficiency.

4.1.2 Real-Time Monitoring and Early Warning

Energy consumption, equipment status, and environmental quality data are collected in real time. Equipment interconnection is facilitated through sensors and IoT technology, enabling the prompt detection of exceptions and the issuance of warnings, thereby mitigating failure risks. For instance, the electrolytic cell temperature warning system oversees the electrolytic process by continuously monitoring the real-time temperature of electrolytic cells to ensure the safety of the potline.

4.1.3 Dynamic Resource Allocation

Resource allocation is optimized through data analysis, including the intelligent scheduling of production plans and energy distribution, aimed at minimizing waste and reducing costs.

4.2 Data-driven Decision Making and Intelligent Analysis

4.2.1 Big Data Analysis

Extensive data is thoroughly analysed to deliver precise decision support, including predictive maintenance and demand analysis for electrolytic cell maintenance, etc.

4.2.2 Visual Presentation

Data is presented in an intuitive manner through 3D modelling, dynamic charts, and various other formats to aid management personnel in swiftly comprehending complex information.

4.2.3 Continuous Optimization Mechanism

Algorithms are employed to continuously enhance operational processes and strategies. This includes adapting work safety training programs to meet the needs of frontline employees, as well as assisting management personnel in dynamically adjusting resource allocation plans.

4.3 Safety and Compliance Assurance

4.3.1 Multi-source Data Integration

The integration of multi-dimensional data, encompassing video surveillance, identity authentication, and behaviour analysis, facilitates the establishment of a comprehensive security protection system. This system includes features such as contractor access monitoring, personnel information QR codes, and operational process data monitoring.

4.3.2 Risk Warning and Emergency Response

Potential risks associated with aluminium electrolysis production are monitored in real time, and emergency response plans are automatically activated to improve the capacity for managing emergencies.

4.3.3 Compliance Management

Operation logs and data flows are recorded to meet audit and compliance requirements.

5. Conclusions

Intelligent safety technologies facilitate targeted management of work safety in aluminium electrolysis through the integration of multiple technologies. This approach effectively and precisely addresses various safety management challenges encountered during the production process, thereby advancing the aluminium electrolysis industry towards a more sustainable, efficient, and safer development trajectory. Future efforts should further integrate AI and IoT technologies to achieve intelligent management throughout the process. Through optimization of technical means, this will promote safe, stable, efficient and sustainable development in aluminium electrolysis production.

6. References

1. International Aluminium Institute, Primary Aluminium Production Statistics 2020–2024, <https://international-aluminium.org/statistics-overview/> (Accessed 8 September 2025).
2. Alex Lowery, Preventing molten metal explosions in smelters, Proceedings of the 42nd International ICSOBA Conference, Lyon, France, 27–31 October 2024, Travaux 53, 87–108.
3. Alex W. Lowery and Liu Jin, Why do some casthouses have catastrophic explosions while others do not?, Proceedings of 43rd International ICSOBA Conference, Nanning, China, 26–31 October 2025, Travaux 54 (this conference).
4. Weining Qi, Jinlin Wang, Secure cloud storage platform in the era of big data, *Journal of Network New Media*, May 18, 2015 (in Chinese).
5. Yuxian He, Research on evidence-based government decision-making models in the era of big data, *China CIO News*, August 20, 2023 (in Chinese).
6. Xiaoli Liu et al., A study on the security hospital construction in the view of hospital management, *China Medical Herald*, May 30, 2014 (in Chinese).
7. Boyou Lu et al., Application of virtual instrument for the Kiwi stem production process, *Journal of Agricultural Mechanization Research*, July 15, 2008, Virtual Instrument 418–1B (in Chinese).