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Research on Dynamic Risk Assessment and Emergency Decision Making of Large Island-Based Petrochemical Industrial Park Based on Multimodal Big Data

Ziming Xu[1]*, Junwei Shi[1,2], Yukun Qi[2], Ying Song[1]

[1]Shandong Technology and Business University, Yantai, Shandong, 264005, China

[2]Shandong Yulong Petrochemical Industrial Park Development Co., Ltd. Longkou, Shandong, 265700, China

ABSTRACT

With the rapid development of offshore petrochemical parks, effective risk management has become paramount. This study proposes an AI-driven solution that integrates large-scale model technology to enable intelligent dynamic risk assessment and emergency decision-making in island-based petrochemical complexes. Through real-time collection and analysis of multi-source data from the park, the research leverages AI's robust data processing capabilities to establish precise dynamic risk evaluation models. These models allow for continuous monitoring, assessment, and early warning of various risks within the facility. Furthermore, based on these risk analysis results, AI-powered models generate scientifically sound emergency response plans, significantly enhancing operational efficiency and crisis management capabilities. The findings demonstrate substantial value in improving safety management standards and ensuring stable operations at offshore petrochemical parks.

KEYWORDS

AI large models; Island petrochemical park; Dynamic risk assessment; Emergency decision-making

1 Introduction

1.1 Research background and significance

Island petrochemical parks, leveraging their unique coastal location, hold a pivotal strategic position in China's industrial layout. Their proximity to ports not only significantly reduces logistics costs for crude oil imports and product transportation but also enables the development of integrated industrial chains through marine resources. These parks serve as vital engines driving regional economic growth and play an irreplaceable role in China's energy security and petrochemical industry upgrading.

However, the safety risks in offshore petrochemical parks are significantly higher than those in inland facilities due to their unique characteristics. From a production perspective, these parks involve dozens of complex processes such as crude oil cracking and olefin synthesis. The hazardous chemicals stored and used daily include flammable alkanes, highly toxic benzene series compounds, and other substances, with individual storage volumes often reaching thousands of tons. Any equipment leakage or operational errors could easily trigger fires, explosions, or toxic substance dispersion accidents. Moreover, the unique marine environment of offshore islands exacerbates safety hazards: high-salt, high-humidity climates accelerate equipment corrosion and aging, shorten the lifespan of critical facilities like pipelines and valves, and increase failure rates. Frequent extreme weather events such as typhoons and storm surges may damage core infrastructure like storage tanks and production facilities, potentially causing secondary disasters. More critically, the relatively isolated nature of offshore areas with fragile ecosystems and poor self-recovery capabilities means that any safety incident would rapidly spread leaked crude oil and chemicals to surrounding waters.

In conclusion, the deep integration of AI large models with safety management in island petrochemical parks not only significantly enhances the precision and efficiency of risk control, but also drives the transformation of safety management models from "post-incident handling" to "preventive measures" and "precise responses during operations". This provides robust technical support for the safe and green development of China's island petrochemical industry.

1.2 Research status at home and abroad

Globally, developed nations have pioneered innovative approaches in AI-powered safety management for chemical industrial parks, establishing replicable best practices. The United States exemplifies this trend, where its advanced chemical industry with stringent safety regulations has seen major facilities adopt machine learning technologies early on. These parks implemented intelligent monitoring systems covering the entire lifecycle of equipment. By deploying high-density sensors on critical components—including reactors, pipelines, and compressors—they collect real-time

*** Corresponding Author:** Zingmi Xu, 2329774297@qq.com

operational data such as temperature, pressure, vibration frequency, and sealing performance. Machine learning algorithms like gradient boosting trees and recurrent neural networks then analyze this data [1]. The algorithms automatically learn operational thresholds and fluctuation patterns, detecting early warning signs 24-72 hours in advance. This proactive approach prevents safety incidents caused by unexpected equipment failures. For instance, a Gulf Coast chemical park in the U.S. achieved a 35% reduction in unplanned downtime and nearly halved emergency response time through this technology.

While developed countries have achieved remarkable progress in this field, specialized research addressing the unique conditions and complex operational processes of island petrochemical parks remains underdeveloped. Current technical solutions predominantly follow designs for inland or conventional coastal chemical zones, failing to adequately account for critical challenges: the interference from high-salt and high-humidity environments , disruptions to communication networks and power systems caused by typhoons , and the special requirements for emergency response due to marine ecosystem fragility . These existing approaches struggle to directly meet the safety management demands of island-based chemical industrial parks.

In China, with the rapid iteration of artificial intelligence technology and the advancement of the "new quality productivity" development strategy, intelligent safety management in chemical industrial parks has become a hot research topic. Scholars and enterprises are actively investing in technological R&D and practical exploration [2]. In the field of risk early warning, some research teams have developed safety risk prediction models by integrating historical accident data, production process parameters, and equipment status information from chemical parks using deep learning algorithms . These models can identify and warn against typical risks like fires, explosions, and toxic substance leaks, demonstrating certain effectiveness in pilot applications within laboratory environments or small inland chemical parks. However, there remain significant shortcomings in model accuracy and scenario adaptability: On one hand, the lack of specialized data for island chemical parks leads to substantial prediction errors in island scenarios, with false alarm rates exceeding 20% in some cases. On the other hand, existing models are predominantly designed for single-risk scenarios, failing to adequately address the complex production processes and multi-risk coupling situations prevalent in island chemical parks, resulting in insufficient adaptability.

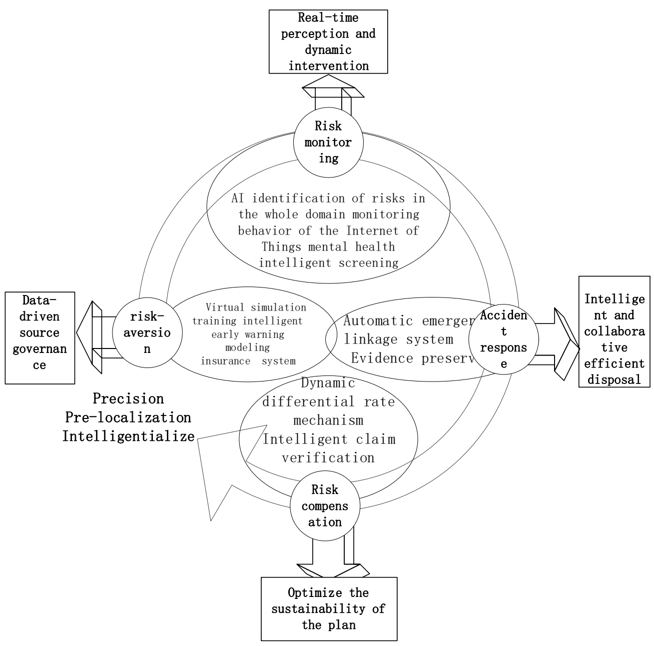

Figure 1 Pathways to risk suppression

2 Risk characteristic analysis of island petrochemical industrial park

2.1 Risks arising from complexity of production processes

The production processes in island petrochemical industrial parks constitute a complex system integrating multidisciplinary technologies [3]. These processes encompass dozens of chemical reactions including catalysis, oxidation, and polymerization, along with numerous physical operations such as distillation, extraction, and heat exchange. Each process is tightly interconnected through pipelines and valves. A single complete crude oil refining unit alone contains hundreds of core devices and tens of thousands of meters of process pipelines, demonstrating a level of complexity far exceeding conventional industrial scenarios.

More critically, the processes are highly interconnected: If oil vapor leakage during distillation is not promptly addressed, it could ignite upon contact with open flames. The intense heat from such flames might overheat adjacent cracking units, potentially causing pressure spikes and explosions. The resulting blast waves would damage reforming unit pipelines, triggering toxic substance leaks that mix with crude oil. This creates a "fire-explosion-toxicity leak" chain reaction. With the island's confined space limiting rescue access, the consequences would escalate exponentially, delivering devastating impacts on lives, industrial assets, and marine ecosystems.

2.2 Risk caused by hazardous chemical characteristics

The hazardous chemicals involved in petrochemical production possess both high risks and severe hazards, including flammable substances like crude oil and gasoline, as well as toxic compounds such as ethylene and hydrogen sulfide. Crude oil and gasoline have extremely low flash points (typically below-40℃), which can ignite violently upon contact with tiny sparks. Ethylene, a flammable gas stored under high pressure, may explode when leaked from pipelines or storage tanks and mixes with air at concentrations within the explosive limit (2.7%-36%). Hydrogen sulfide, a highly toxic gas, causes respiratory irritation even at 10ppm concentrations. Exposure to concentrations exceeding 1000ppm can lead to fatal suffocation within seconds. These substances' unique properties make comprehensive lifecycle management particularly challenging.

During storage, transportation, and usage, hazardous chemicals are highly sensitive to environmental factors. During storage, if the temperature control system in storage tanks fails, high temperatures may increase vapor pressure of liquids like gasoline and crude oil, potentially cracking tank seals and causing leaks. In maritime transport, high humidity accelerates pipeline corrosion, increasing leakage risks. During use, excessive pressure fluctuations in reaction systems can lead to gas leaks like ethylene, which may trigger safety incidents.

2.3 Impact of marine environmental factors

Island petrochemical industrial parks, situated in marine environments, are subject to various oceanic factors including waves, tides, sea winds, and storm surges. These elements may damage park facilities and disrupt normal operations [4]. For instance, powerful typhoons could cause offshore platforms to collapse or oil pipelines to rupture, potentially triggering crude oil leaks that severely damage marine ecosystems. Additionally, the corrosive nature of the marine environment accelerates equipment aging and deterioration, significantly increasing safety risks.

From an operational perspective, the periodic forces of ocean waves and tides continuously impact the park's coastal protection systems. Persistent tidal surges erode the shoreline foundation, causing cracks in breakwaters and concrete spalling [5]. If left unrepaired, these fissures will gradually widen, endangering the structural integrity of downstream storage tanks and facility zones. Meanwhile, tidal fluctuations alter water levels in the park's low-lying areas. When tide levels exceed drainage system elevation thresholds, rainwater can backflow into pipelines, leading to electrical equipment moisture-induced short circuits. This destabilizes critical production units like pumps and compressors, significantly increasing risks of unplanned shutdowns.

The impact of sea winds cannot be overlooked. This corrosive substance damages anti-corrosion coatings and accelerates electrochemical corrosion —— such as at oil pipeline joints where corrosion reduces sealing performance and causes crude oil leakage. Corroded sensor data leads to inaccurate measurements, potentially causing operational errors that compromise precision control in production processes [6]. Furthermore, prolonged exposure to strong sea winds subjects open-air equipment supports and pipeline structures to continuous loads, causing steel fatigue deformation and reducing equipment lifespan.

Of particular concern is the persistent corrosiveness of marine environments. Beyond salt spray, seawater's high chloride ion concentration causes penetrating corrosion to underground pipelines and equipment foundations within industrial parks. For instance, when concrete tank foundations remain exposed to seawater for extended periods, they develop steel reinforcement corrosion and concrete loosening, leading to tank tilting [7]. Severe cases may result in tank ruptures and oil spills. Similarly, when buried oil pipelines develop holes due to seawater corrosion, this not only causes oil loss but also contaminates surrounding soil and groundwater, exacerbating safety and environmental risks. These corrosive effects are often hidden and cumulative – initially undetectable but becoming critical threats to production safety once they erupt.

2.4 Personnel and operational risks

The petrochemical industry requires a large number of skilled professionals for operations and management. Workers' safety awareness, operational skills, and sense of responsibility directly impact production safety. Without proper training, unfamiliarity with operating procedures, or violations of safety protocols can easily lead to accidents. For instance, operators conducting unauthorized hot work in flammable/explosive zones or failing to wear personal protective equipment as required may become the spark that ignites an accident.

The petrochemical production process involves complex operations under high-temperature, high-pressure, and hazardous conditions including flammability, explosiveness, and toxicity. Every stage—from raw material processing to catalytic reactions and product separation—demands precise technical execution and scientific management. Workers' safety awareness, operational skills, and sense of responsibility form the "three-tier defense" system for production safety [8]. Any breach in this chain can trigger a domino effect of accidents. These seemingly minor violations could lead to accidents when gas concentrations exceed explosive limits or toxic thresholds. Particularly during continuous shift operations, fatigue-induced safety lapses may cause delayed detection of equipment abnormalities , missing critical early-stage intervention opportunities. Similarly, when switching material transfer pipelines, inadequate purging of residual media may trigger chemical reactions between different materials, generating flammable substances. Moreover, in cases of sudden equipment failures , inexperienced personnel might fail to quickly identify fault causes or activate emergency response plans, potentially escalating accidents [9]. Therefore, strengthening safety training, skill assessments, and accountability education for technical personnel remains the cornerstone of ensuring petrochemical production safety.

3 Technical principles and advantages of AI large model

3.1 Know-why

AI large models typically employ the Transformer architecture, which utilizes attention mechanisms to effectively process sequential data and capture long-range dependencies. During training, these models undergo unsupervised or supervised learning through extensive data, continuously adjusting parameters to enhance their understanding and predictive capabilities [10]. In data analysis tasks, they analyze data distribution patterns and evolving trends to enable classification, prediction, and anomaly detection capabilities.

3.2 Advantages in risk assessment and emergency decision making

The system efficiently processes massive multi-source data streams, including equipment operation metrics, environmental monitoring parameters, and operational personnel records, providing comprehensive data support for risk assessment. As new data continues to be fed into the system, the model continuously learns and optimizes, improving both the accuracy and adaptability of risk assessment and emergency decision-making processes.

4 Dynamic risk assessment model integrating AI large model is constructed

4.1 Multi-source data acquisition and preprocessing

4.1.1 Sources of date

Collect equipment sensor data from petrochemical industrial parks in island areas to obtain operational status information such as temperature, pressure, and flow rate. Gather environmental monitoring data including meteorological parameters , marine environment data , and hazardous gas concentration data. Record operator activity details including login credentials, operation timestamps, and task descriptions. Simultaneously collect historical incident data for model training and validation purposes.

4.1.2 Data preprocessing

Clean the collected data by removing noise and outliers. Standardize data by converting different types of data into a unified format and scale for model processing. Fill in missing data using methods like mean imputation, interpolation techniques, or machine learning algorithms to ensure data integrity.

4.2 Construction of risk index system

4.2.1 Identifying risk indicators

Risk indicators are established through four key dimensions: personnel, equipment, environment, and management. Personnel-related metrics include training proficiency levels and frequency of non-compliance incidents. Equipment-related metrics encompass equipment failure rates and aging severity. Management-related metrics cover the completeness of safety management systems and the frequency of safety inspections.

4.2.2 Indicator weights are determined

The weight of each risk index is determined by using the analytic hierarchy process (AHP). By means of expert scoring, the judgment matrix is constructed to calculate the relative weight of each index, so as to reflect the influence degree of different indexes on risks.

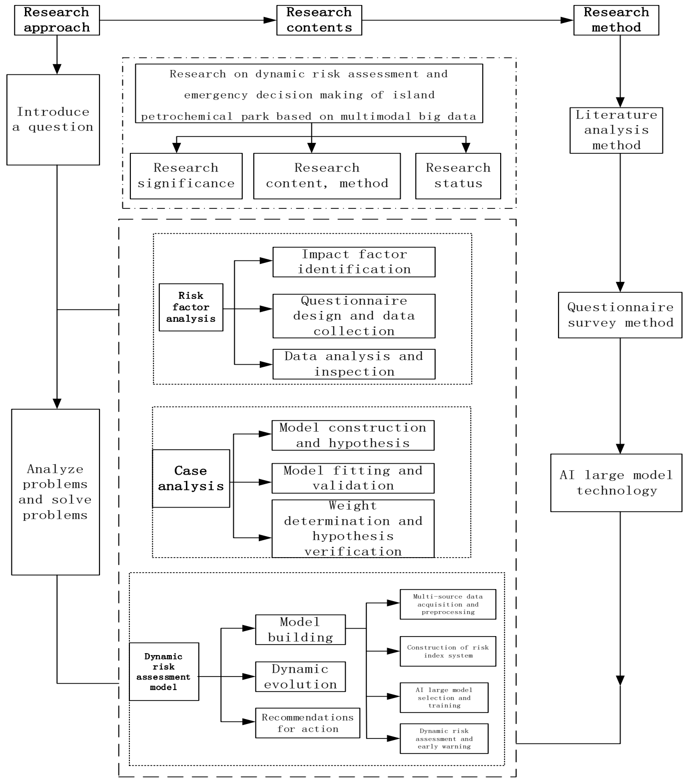

Figure 2 Technology road map

5 Emergency decision support system based on risk analysis

5.1 Emergency decision process design

The Emergency Decision Support System continuously receives real-time risk assessment results and early warning alerts from dynamic risk evaluation models. By analyzing these assessments alongside the park's emergency response plans and historical accident cases, it predicts potential incident scenarios—including their types, scales, and impact areas. Feedback collected during implementation is used to promptly refine and improve the plans.

5.2 Application of AI large model in emergency decision making

The AI-powered large model dynamically formulates emergency resource allocation plans by analyzing accident scenarios, risk assessments, and the distribution of emergency resources within industrial parks. This intelligent system optimizes resource distribution to enhance rescue efficiency[10]. Through learning from historical accident cases and real-time data, the model provides scientific guidance for emergency response strategies.

5.3 System integration and visual presentation

Integrate the emergency decision support system with other park information systems such as production management systems, safety monitoring systems, and Geographic Information Systems to achieve data sharing and interaction, thereby enhancing system collaboration. This provides decision-makers with clear analytical foundations, facilitating effective command and dispatch operations.

6 Conclusions and outlook

6.1 Summary of research findings

Through analyzing risk characteristics in offshore petrochemical parks, this study integrates AI large model technology into dynamic risk assessment and emergency decision-making processes, establishing an AI-powered dynamic risk assessment model and emergency decision support system. Case studies demonstrate that this methodology effectively elevates safety management standards in offshore petrochemical parks.

6.2 Future research direction outlook

Future research can be developed in the following areas: First, further optimize the architecture and algorithms of large AI models to enhance their accuracy and adaptability, enabling better handling of complex and ever-changing risk environments in island petrochemical parks [11]. Second, strengthen the integration of multimodal data by combining video/image data, voice data with traditional sensor information to diversify risk assessment sources. Third, conduct ethical and legal research on AI model applications in chemical park safety management to ensure responsible technology implementation. Fourth, promote the adoption of AI model technologies across more island petrochemical parks, continuously refining technical solutions through practical application to provide robust support for the safe development of China's petrochemical industry.

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About the Author

Ziming Xu,Undergraduate, Safety Engineering.

References

[1] Jiang Guan, Liu Ziyang. Barriers and Countermeasures for Deep Integration of Large Model Technology with Archival Compilation and Research [J]. Shanxi Archives, 2025, (09):1-6.

[2] Li Chenlin. Decision-Making on Yunnan Province's Earthquake Emergency Response Levels Based on Bayesian Optimization-Support Vector Machine Model [J]. Occupational Health & Emergency Rescue, 2025,43(04):530-535.

[3] Liu Hanwen, Huang Lingyao. Integration Innovation and Development Path of Domestic AI Large Model Technology in Film Industry [J]. Modern Film Technology, 2025, (08):4-11.

[4] Gu Mingsheng. Application Research on Multimodal Data Fusion and Large Model-Driven Intelligent Agent Systems in Smart Cities [J]. Changjiang Information & Communication, 2025,38(08):231-233.

[5] Shu Weizhe, Wang Zengqiang. Enterprise Emergency Decision-Making Methods in Uncertain Environments —— Analysis Based on Multi-granularity Binary Semantics and Prospect Theory [J]. Journal of Zhengzhou Institute of Aeronautical Industry Management (Social Sciences Edition), 2025,44(04):33-39+99.

[6] Han Hui. Architecture Research on Intelligent Emergency Decision-Making System for Disaster Relief Based on Large Language Models [J]. Cybersecurity & Informatization, 2025, (08):71-73.

[7] Wu Feng, Zheng Xiaolin. Frontier Trends, Risk Assessment, and Implications of Artificial Intelligence Applications in Publishing Industry of Developed Countries [J]. Social Sciences Frontiers, 2025, (07):150-158.

[8] Guo Hangfei. Research on Dynamic Fire Risk Assessment Model for Commercial Premises [D]. China University of Mining and Technology, 2023.

[9] Yu Zhengrong, Zhang Tong, Luo Jianyu, et al. Study on Public Transport Safety Risk Assessment and Early Warning Information System [J]. Safety, 2021,42(08):20-24.

[10] Zhang Renkun, Chen Yong, Wang Yuhua, et al. New Design Concepts for Island-type Petrochemical Base [J]. Journal of Zhejiang Ocean University (Natural Science Edition), 2018,37(01):87-90.

[11] Guo Jian, Chen Ying. Strategic Research on the Construction of Island-type Petrochemical Parks in China [J]. Management Observation, 2016, (32):83-84+87.