

Research on Emergency Management Dilemmas and Safety Control Strategies for Large-Scale Island-Based Petrochemical Industrial Parks

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ABSTRACT

Large-scale petrochemical industrial parks are the core carriers of China's energy and chemical industries. Their safe production and emergency management are closely related to national economic security, social stability and ecological protection. The traditional management model dominated by a single enterprise or government is difficult to deal with the increasingly complex systemic risks in the park. Based on a multi-subject collaborative perspective, this article deeply analyzes the main predicaments existing in the safety and emergency management of current large-scale petrochemical parks, including issues such as ambiguous rights and responsibilities among subjects, high information barriers, insufficient collaborative motivation, fragmented resource allocation, and disconnection in emergency response. In response to these predicaments, this article proposes a systematic development path: establishing a collaborative governance structure of "government-led - corporate responsibility - social participation"; Build an intelligent information sharing and emergency command platform; Improve the institutionalized and standardized collaborative mechanism; Cultivate an open and mutually trusting security culture ecosystem; And carry out regular and practical collaborative drills. The aim is to achieve a profound transformation from fragmented management to systematic governance by enhancing the collaborative efficiency of multiple entities, and to lay a solid foundation for the safe development of the park.

KEYWORDS

Petrochemical industrial park; Multi-subject collaboration; Safety management; Emergency management; Collaborative governance

1 Introduction

With the deep integration of industrialization and urbanization in our country, large-scale petrochemical parks, relying on their significant industrial agglomeration effects and circular economy advantages, have become important engines for regional economic development. However, while the park is generating huge economic benefits, it also forms a "high-risk energy field" due to the accumulation of a large number of high-risk devices, hazardous chemicals and complex process flows within it ^[1]. Once an accident occurs, it is very likely to trigger a "domino effect", leading to disastrous consequences. The extremely serious accidents such as the "August 12" incident at Tianjin Port and the "March 21" incident in Xiangshui, Jiangsu Province, have served as extremely painful lessons to warn us that the traditional single and linear safety management model is no longer capable of effectively dealing with the complex risk systems in modern parks ^[2].

The safety risks in modern petrochemical parks have typical characteristics of systematicness, coupling and dynamics. Its management involves multiple heterogeneous entities such as the park management committee, various government regulatory departments, numerous enterprises within the park (including upstream and downstream enterprises and public utility units), third-party service institutions, surrounding communities, and even the general public. These subjects have different goals, diverse resources and asymmetric information, and there are complex interactive relationships among them. The failure of any single entity or the disruption of coordination among entities may become a "weak link" in the entire security defense line. Therefore, from the perspective of multi-subject collaboration, examining the safety and emergency management issues of the park, breaking down organizational barriers, integrating scattered resources ^[3] This article aims to conduct an in-depth exploration on this issue, with the expectation of providing theoretical references and practical guidance for the safe and sustainable development of large-scale petrochemical parks in China ^[4].

2 The theoretical connotation of multi-subject collaboration and its necessity in the safety management of industrial parks

2.1 Theoretical connotation of multi-subject collaboration

The multi-agent collaboration theory originated from synergetics. Its core essence lies in that in an open system,

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numerous subsystems with different natures can generate a "1+1>2" synergy effect through nonlinear interactions, enabling the system to move from disorder to order and from dispersion to unity. When applied in the field of public administration, it emphasizes the diversity and equality of governance subjects.

In the context of large-scale petrochemical industrial parks, multi-party collaboration refers to the goal of enhancing the overall safety and resilience of the park.^[5] It involves government regulatory departments such as the park management committee, emergency management, ecological environment, transportation, and fire control, enterprises within the park, professional forces such as fire rescue and medical rescue, third-party institutions such as safety assessment and environmental monitoring, as well as social entities such as surrounding communities and media. Through institutionalized communication channels, shared information platforms and joint action processes, a security governance community that is organically linked and highly efficient in response is formed.

2.2 The necessity of multi-party collaboration

2.2.1 The inevitable choice to deal with the complexity of risks

Park risks are a complex interwoven of technical risks, organizational risks and social risks. A single enterprise cannot independently deal with cross-enterprise chain risks, and the government's "one-size-fits-all" supervision is also difficult to cover all management details^[6].

2.2.2 The objective requirement for integrating scattered resources

Each entity possesses heterogeneous emergency resources (such as professional response teams from enterprises, authoritative command from the government, evacuation sites in communities, and technical support from third parties).

2.2.3 The key to enhancing the efficiency of emergency response lies in the fact that every second counts in accident emergency response

Multi-headed command, delayed information and conflicting actions are the major taboos in emergency response. The pre-established collaborative mechanism can ensure that a unified command, clear division of labor and well-coordinated response pattern is quickly formed in emergency situations, minimizing the losses caused by accidents to the greatest extent^[7].

3 The main predicaments of Park Safety and emergency Management from the perspective of Multi-subject collaboration

Although the necessity of collaboration has become a consensus, in practice, most petrochemical parks in our country still face the following deep-seated collaborative predicaments:

3.1 Ambiguous rights and responsibilities of the main body and loose structure of collaborative governance

The safety management of the park involves multiple departments of "vertical and horizontal" levels, and there is a coexistence of overlapping responsibilities and regulatory gaps. The management committee often lacks sufficient authority and law enforcement power to coordinate the vertical management departments dispatched by the higher-level government^[8].

3.2 High information barriers and weak foundation for collaborative decision-making

Each subject's information system is independently built, with inconsistent data standards and formats, resulting in a large number of "information silos". Divergence in interest goals and insufficient internal driving force for collaboration. The government pursues security and stability, enterprises pursue profits and efficiency, and communities focus on health and the environment. The inconsistency of goals leads to the difficulty in synchronizing actions. Safety investment has negative externalities^[9].

3.3 Fragmented resource allocation and limited collaborative emergency response capabilities

The emergency rescue teams, equipment, and materials of each enterprise mainly serve their own units, lacking a unified planning, allocation, and dispatching mechanism at the park level.

3.4 Severe formalization of drills and disconnection of collaborative response mechanisms

Many emergency drills in parks tend to be "scripted" and "evolutionary", with pre-set processes and results, failing to truly test the effectiveness of the collaborative mechanism^[10].

4 Analysis of typical cases of multi-party collaboration in domestic and international chemical industrial parks

4.1 Negative case: coordination failure in the "3-21" extremely serious explosion accident in Xiangshui, Jiangsu province

The explosion accident that occurred at Xiangshui Tianjiayi Company in 2019 is a typical example of the complete failure of multi-party collaboration.

4.1.1 Information barriers and regulatory failures

The enterprise has long concealed the types and quantities of hazardous chemicals stored, and the internal management data is seriously inconsistent with the data reported to the government.

4.1.2 Emergency response was chaotic and disorderly

After the accident, there was a lack of a unified emergency command center, and communication among various rescue forces was poor, with unclear information. In the early stage, the distribution of hazardous chemicals within the factory area was not accurately grasped, which affected the scientific nature of rescue decisions and exposed the fatal flaws of the plan being divorced from actual combat and the collaborative drills being merely formalities.

4.2 Positive case: collaborative practice on Jurong Island, Singapore

Jurong Island in Singapore is a world-recognized model for safety management in chemical industrial parks, and the core of its success lies in outstanding multi-party collaboration.

4.2.1 A sound legal system and clear rights and responsibilities

The Singaporean government has clarified the safety responsibilities of the government, enterprises and other stakeholders through laws and regulations such as the Fire Safety Act and the Dangerous Goods Act. The governing body of Jurong Island has been granted full authority and resources to coordinate the island's security planning, infrastructure and emergency response^[11].

4.2.2 Highly Integrated emergency response system

A unique, integrated emergency response center has been established on the island, integrating police, civil defense forces (SCDF), corporate emergency teams and medical resources. All rescue forces use a unified communication frequency and command system, and regularly conduct joint exercises to ensure seamless connection in emergency response.

4.2.3 All-round information sharing and technological innovation

The park mandates that enterprises share key security data and has established a sensor network and central monitoring system covering the entire island to achieve real-time monitoring and early warning of risks. Widely adopt technologies such as digital twins for simulation, deduction and training.

4.2.4 A deeply ingrained safety culture

Through the in-depth promotion of the "Responsible Care" concept, safety has been elevated to a common value and self-regulatory behavior of all enterprises in the park, forming a favorable ecosystem that transcends contractual constraints and actively shares safety knowledge and best practices.

The experience of Jurong Island has proved that it is feasible and efficient to achieve high-level multi-subject collaboration through top-level design, technological empowerment and cultural guidance.

5 Development paths and countermeasures for promoting multi-subject collaboration

To break through the above-mentioned predicament, it is necessary to carry out systematic reform and innovation, and build a multi-subject collaborative governance system with clear rights and responsibilities, information sharing, sufficient motivation and efficient actions.

5.1 Build a collaborative governance structure featuring "government leadership - enterprise responsibility - social participation"

5.1.1 Strengthen the leading role of the government

Enhance the overall coordination level and authority of the park management committee. Through legislation or administrative authorization, clearly define its coordinating and commanding power over various regulatory institutions

stationed in the park.

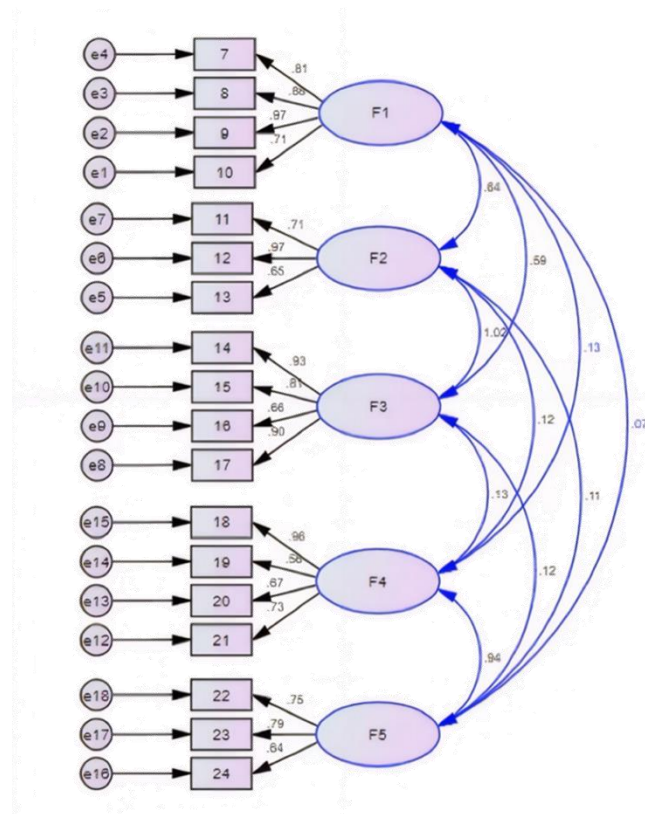


Figure 1 Structural equation model

5.1.2 Guide the orderly participation of society

Establish an information communication and hearing mechanism with the surrounding communities to ensure the public's right to know and supervise. Introduce third-party professional institutions to provide services such as security audits, risk assessments, and emergency consultations to enhance the scientific and fair nature of governance.

5.2 Improve the institutionalized and standardized collaborative mechanism

5.2.1 Improve the legal and standard system

Formulate unified guidelines for the formulation of emergency response plans, information sharing standards, emergency rescue procedures and technical standards for the park to ensure that collaborative actions are carried out in accordance with established rules.

5.2.2 Establish a dynamic mechanism that emphasizes both incentives and constraints

Implement a credit evaluation system for work safety, link the collaborative performance of enterprises with credit, insurance, project approval, etc., and offer rewards to those with outstanding performance. Joint disciplinary actions should be taken against entities that conceal information or shirk responsibility, creating a clear orientation of "rewarding trustworthiness and punishing untrustworthiness".

5.3 Cultivate an open and mutually trusting security culture ecosystem

Regularly open the science popularization and education base to the public, transparently disclose the safety conditions of the park, and eliminate the NIMBY effect.

5.4 Carry out regular and practical collaborative drills

5.4.1 Implement "double-blind" drills

Unscheduled drills without prior notice of time and location, and without setting fixed scripts, are conducted to truly test the emergency preparedness levels and collaborative response capabilities of all entities.

5.4.2 Strengthen comprehensive drills of all elements

The drill must cover the entire process, including early warning release, initial response, personnel evacuation, medical rescue, environmental monitoring, public opinion guidance, and post-event recovery, and incorporate all relevant entities.

6 Development paths and countermeasures for promoting multi-subject collaboration

6.1 Build a collaborative governance structure featuring "government-led - corporate responsibility - social participation"

6.1.1 Strengthen the leading role of the government

Enhance the overall coordination level and authority of the park management committee. Through legislation or administrative authorization, clearly define its coordinating and commanding power over various regulatory institutions stationed in the park. Establish a work safety committee led by the Management committee and composed of departments.

6.1.2 Strengthen the primary responsibility of enterprises

Through laws, regulations and the park access system, the legal responsibilities of enterprises in aspects such as joint risk prevention, information reporting and emergency mutual assistance should be clearly defined. Implement the "chain leader system", with leading enterprises within the park taking the lead to establish a security alliance among upstream and downstream enterprises.

6.1.3 Guide the orderly participation of society

Establish an information communication and hearing mechanism with the surrounding communities to ensure the public's right to know and supervise.

6.2 Build an intelligent information sharing and emergency command platform

6.2.1 Build a "smart safety brain" for the park

By leveraging technologies such as the Internet of Things, big data, BIM, and 5G, a unified perception network and data middle platform covering the entire park will be constructed. Force access to key data such as major hazard source monitoring, environmental protection monitoring, and emergency supplies of enterprises to break down information barriers.

6.2.2 Achieve data-driven collaboration

Based on platform data, dynamic risk assessment, intelligent early warning and trend prediction are achieved.

6.3 Improve the institutionalized and standardized collaborative mechanism

6.3.1 Improve the legal and standard system

Promote the introduction of local regulations or park management rules to provide legal basis for multi-party collaboration. Formulate unified guidelines for the formulation of emergency response plans, information sharing standards, emergency rescue procedures and technical standards for the park to ensure that collaborative actions are carried out in accordance with established rules.

6.3.2 Establish a dynamic mechanism that emphasizes both incentives and constraints

and offer rewards to those with outstanding performance. Joint disciplinary actions should be taken against entities that conceal information or shirk responsibility, creating a clear orientation of "rewarding trustworthiness and punishing untrustworthiness".

6.4 Cultivate an open and mutually trusting security culture ecosystem

6.4.1 Promote cultural integration

Regularly open the science popularization and education base to the public, transparently disclose the safety conditions of the park, and eliminate the NIMBY effect. Encourage enterprises to share best practices and lessons learned from accidents within and among themselves, and foster a cultural atmosphere of "shared governance".

6.5 Carry out regular and practical collaborative drills.Strengthen comprehensive drills of all elements

The drill must cover the entire process, including early warning release, initial response, personnel evacuation, medical rescue, environmental monitoring, public opinion guidance, and post-event recovery, and incorporate all relevant entities.

7 Conclusion

The safety and emergency management of large-scale petrochemical industrial parks is a complex mega-system issue. No single entity's "going it alone" is capable of addressing the systemic risk challenges. From the perspective of multi-

subject collaboration, the root cause of the current management predicament in the park lies in the loose governance structure, the obstruction of information flow, the lack of internal motivation and the fragmentation of emergency response capabilities.

The solution lies in carrying out a profound governance reform, shifting from the traditional administrative management mindset to a modern collaborative governance mindset. By establishing a clear governance structure, creating an intelligent information platform, improving institutionalized mechanisms, fostering a cultural ecosystem of mutual trust and conducting practical exercises, we will systematically and continuously promote the transformation of multiple entities such as the government, enterprises and society from physical superposition to chemical integration, and ultimately form a community with a shared future for safe development featuring shared rights and responsibilities, information sharing, synchronized actions and shared honor and disgrace. This is not only the inevitable way to enhance the intrinsic safety level of the park, but also an important guarantee for achieving high-quality regional economic development and social harmony and stability.

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