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Research on Safety Strategy of Oil and Gas Pipeline Networks

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Abstract **Original Research Article**

As the key strategic infrastructure of the energy system, the safe and stable operation of oil and gas pipeline networks is directly related to national energy security, economic development and ecological environmental protection. With the continuous expansion of pipeline network scale, the continuous complexity of operation conditions and the continuous emergence of new safety risks, the traditional passive safety management mode can no longer adapt to the high-quality development requirements of modern pipeline networks. This paper takes the safety development of oil and gas pipeline networks as the research object, analyzes the strategic challenges faced by pipeline network safety from the aspects of full-life cycle safety management, intelligent safety construction, risk resilience improvement and industry standard system construction. Combining the development trend of global pipeline safety technology and management experience, it constructs a multi-dimensional safety strategy system covering technical innovation, management optimization, system guarantee and emergency resilience. The research proposes strategic paths such as full-life cycle safety control, intelligent safety empowerment, standardized system construction and regional collaborative safety management. The results can provide theoretical support and strategic reference for improving the overall safety level of oil and gas pipeline networks, preventing major safety accidents, and promoting the high-quality and safe development of the pipeline energy industry.

Keywords: oil and gas pipeline network; safety strategy; full-life cycle management; intelligent safety; risk resilience.

1. Introduction

Under the background of global energy transformation and energy supply chain security strategy, oil and gas pipeline networks, as the main channel of fossil energy transportation, undertake the important strategic mission of ensuring stable energy supply. In recent decades, the global oil and gas pipeline industry has developed rapidly, forming a cross-regional, large-scale and networked pipeline transportation system. However, with the aging of early built pipelines, the diversification of laying environments, the frequent occurrence of extreme natural disasters and the increase of human engineering activities, the safety operation pressure of pipeline networks is increasing day by day, and new safety problems and strategic challenges continue to emerge.

Pipeline network safety is a systematic and strategic project, which runs through the whole process of pipeline design, construction, operation, maintenance and scrapping. At present, the safety construction of oil and gas pipeline networks in most regions still has problems such as disjointed full-cycle management, insufficient intelligent safety

application, imperfect standard system and weak regional collaborative prevention and control. The traditional safety management mode focusing on post-accident disposal cannot adapt to the strategic requirements of modern pipeline network safety development. Therefore, it is urgent to carry out systematic research on pipeline network safety strategy, build a long-term safety development mechanism, and realize the transformation of pipeline network safety management from passive disposal to active prevention, from single point management to systematic governance, and from experience management to intelligent governance, so as to consolidate the strategic foundation of energy pipeline safety.

2. Strategic Challenges for Oil and Gas Pipeline Network Safety Development

2.1 Deficiencies in Full-Life Cycle Safety Management

The safety management of oil and gas pipeline networks has obvious whole-life cycle characteristics, and the safety quality of each link of design, construction, operation and maintenance affects the overall safety performance of the pipeline system. At present, many pipeline projects have the problem of emphasizing construction and neglecting management. In the design stage, the adaptability of pipeline layout to complex geological environment and extreme weather is not fully considered, resulting in inherent safety hidden dangers of pipeline design. In the construction stage, non-standard construction processes and unqualified anti-corrosion treatment reduce the initial safety performance of pipelines.

In the operation and maintenance stage, the long-term overload operation and irregular detection and maintenance lead to the continuous accumulation of pipeline safety risks. The disjointed management of each life cycle link leads to the inability to form a closed-loop safety management system, and potential risks cannot be eliminated fundamentally, which restricts the long-term safe operation of pipeline networks.

2.2 Insufficient Intelligent Safety Technology Application

Intelligent technology is the core driving force of modern pipeline network safety strategy upgrading. At present, the intelligent construction of oil and gas pipeline networks is uneven. Most traditional pipeline networks still rely on manual inspection and empirical judgment for safety management, with low monitoring accuracy and poor timeliness of risk early warning. Although some new pipeline networks are equipped with intelligent monitoring equipment, there are problems such as isolated data systems, insufficient data mining ability and low intelligent decision-making level.

The lack of deep integration of digital twin, big data analysis, machine learning and other intelligent technologies with pipeline safety management leads to the inability to realize dynamic risk prediction, intelligent fault diagnosis and precise safety control. The backward intelligent safety technology has become an important bottleneck restricting the strategic upgrading of pipeline network safety.

2.3 Imperfect Safety Standard and Supervision System

The construction of pipeline network safety standard system is the institutional guarantee for standardized safety management. At present, the existing pipeline safety standards and supervision systems have lagged behind the development of large-scale and networked pipeline systems. The safety standards for complex working conditions such as cross-river, mountainous and urban intensive pipeline sections are not perfect, and there is a lack of targeted safety management specifications.

In terms of supervision mechanism, there are problems such as overlapping supervision and blind spots in supervision. The division of responsibilities between government supervision departments, operation enterprises and third-party detection institutions is not clear, resulting in insufficient supervision force and inadequate implementation of safety management responsibilities. The imperfect institutional system restricts the standardized and long-term development of pipeline network safety

management.

2.4 Weak Risk Resilience and Emergency Strategic Capability

Modern pipeline network safety strategy requires strong risk resilience and emergency response capability to cope with sudden disasters and accidents. At present, most pipeline networks have weak risk resistance and recovery capability. In the face of extreme natural disasters and major sudden accidents, the pipeline network system is prone to large-scale failure, and the system recovery speed is slow after accidents. In addition, the emergency strategy system is not perfect, lacking long-term emergency planning, multi-scenario accident disposal plans and regional collaborative emergency mechanisms. The insufficient reserve of emergency resources and the low level of professional emergency disposal restrict the improvement of pipeline network safety strategic resilience.

3. Overall Framework of Pipeline Network Safety Strategic System

Based on the current safety challenges and development needs of oil and gas pipeline networks, this paper constructs a four-dimensional integrated safety strategic system including full-life cycle safety control, intelligent safety technology empowerment, standardized institutional system guarantee and resilient emergency response capability improvement, aiming to realize systematic, intelligent and standardized safety governance of pipeline networks.

3.1 Full-Life Cycle Safety Control Strategy

Implement full-life cycle closed-loop safety management covering design, construction, operation, maintenance and scrapping. In the design stage, optimize the pipeline layout scheme according to the geological environment, meteorological conditions and regional development planning, and improve the pipeline design safety redundancy. In the construction stage, strictly standardize the construction process, strengthen the quality inspection of pipeline welding, anti-corrosion and laying, and eliminate inherent construction hidden dangers.

In the operation and maintenance stage, formulate regular detection, maintenance and renovation plans, carry out dynamic risk assessment of pipeline operation status, and realize timely elimination of potential risks. In the scrapping stage, standardize the pipeline abandonment and disposal process to avoid secondary safety and environmental risks. Through full-cycle whole-process control, build a closed-loop safety management system to ensure the long-term safe operation of the pipeline network.

3.2 Intelligent Safety Empowerment Strategy

Take digital intelligence technology as the core to promote the intelligent upgrading of pipeline network safety management. Build a unified pipeline network big data platform to integrate monitoring data, detection data, maintenance data and accident data, and realize centralized management and intelligent analysis of safety data. Apply digital twin technology to build a virtual simulation model of the pipeline network, realize dynamic simulation of pipeline operation status, real-time early warning of risks and intelligent prediction of faults.

Adopt machine learning and artificial intelligence algorithms to mine the correlation law of pipeline risk factors, build an intelligent risk assessment and decision-making system, realize automatic identification, grading and disposal of safety risks, and improve the precision and intelligence level of pipeline network safety management.

3.3 Standardized Institutional System Guarantee Strategy

Improve the industry standard system of pipeline network safety management, formulate targeted safety technical specifications and management standards for complex working conditions and new-type pipeline networks, and fill the standard blank of pipeline safety management. Optimize the safety supervision mechanism, clarify the safety

supervision responsibilities of government departments, the main safety responsibilities of operation enterprises and the supervision responsibilities of third-party institutions, and form a multi-party collaborative supervision pattern.

Establish a safety assessment and accountability mechanism, take pipeline network safety operation status as an important assessment index of enterprise operation, strengthen the implementation of safety responsibilities, and standardize the whole process of pipeline network safety management through institutional constraints.

3.4 Resilient Emergency Safety Strategy

Focus on improving the risk resistance and emergency recovery capability of the pipeline network system. Optimize the pipeline network structure layout, improve the network redundancy and fault tolerance, and reduce the cascading failure risk of the pipeline network. Build a multi-scenario emergency plan system covering leakage, explosion, geological disaster and extreme weather accidents, and refine emergency disposal processes and responsibility division.

Establish a regional collaborative emergency linkage mechanism, realize resource sharing and rapid joint disposal of cross-regional pipeline accidents. Strengthen the reserve of professional emergency equipment and materials, carry out regular emergency drills and professional training, and improve the rapid response, on-site disposal and post-accident system recovery capability of the pipeline network, so as to build a resilient safety guarantee system.

4. Strategic Implementation Path and Development Prospect

The implementation of oil and gas pipeline network safety strategy needs to adhere to the principle of systematic governance, technological innovation and long-term mechanism construction. First, strengthen technological innovation investment, accelerate the integration and application of intelligent safety technologies, and promote the transformation of safety management mode. Second, promote institutional standardization construction, improve the safety standard and supervision system, and lay a solid institutional foundation for safety development. Third, strengthen talent team construction, cultivate professional pipeline safety management and technical talents, and provide talent support for strategic implementation. Fourth, promote regional collaborative safety governance, break regional management barriers, and realize joint prevention and control of cross-regional pipeline network safety risks.

In the future, with the continuous development of digital intelligence technology and the continuous improvement of the safety management system, the oil and gas pipeline network safety construction will develop towards full intelligence, full-cycle refinement and full-scenario resilience. The safety strategic system will effectively solve various safety risks and hidden dangers in pipeline network operation, comprehensively improve the overall safety level of the pipeline energy system, and provide solid support for national energy security and stable economic development.

5. Conclusion

The safety development of oil and gas pipeline networks faces multiple strategic challenges such as insufficient full-cycle management, backward intelligent technology, imperfect system and weak emergency resilience. To solve these problems, it is necessary to build a multi-dimensional safety strategic system based on full-life cycle control, intelligent technology empowerment, standardized system guarantee and resilient emergency response. Through systematic strategic layout and precise implementation paths, the passive safety management mode of pipeline networks can be fundamentally changed, the ability of pipeline networks to resist risks and cope with sudden accidents can be comprehensively improved, and the long-term safe, stable and efficient operation of oil and gas pipeline networks can be guaranteed, which has important strategic significance for promoting the sustainable and healthy development of the energy industry.

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