

Research and Application of QHSE Information-based Management and Control System for Offshore Drilling Based on Bow-tie Model

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ABSTRACT

In view of the high-risk characteristics of offshore drilling and the limitations of traditional management modes, a QHSE information-based management and control system based on the Bow-tie model is constructed. The system covers seven major modules, including safety production situation perception, data consultation, inspection form maintenance, and inspection tasks. It integrates fault tree and event tree analysis, and combines the safety barrier theory and the Swiss cheese model to realize closed-loop management of risk identification, prevention and control, emergency response, and hidden danger investigation. This system continuously promotes the development of QHSE management towards digital intelligence, informatization, and high efficiency.

Keywords: *Bow-tie model, QHSE information-based management and control system, Offshore drilling.*

1. INTRODUCTION

Offshore drilling, as a key field of energy development, is characterized by high investment, high risk, and high technology intensity. Its operating environment is complex and volatile, significantly influenced by factors such as marine meteorology and geological conditions, making it highly prone to accidents including blowouts, fires, and environmental pollution. These accidents pose severe threats to personnel health, equipment safety, and the marine ecological environment. Therefore, constructing a scientific and efficient QHSE information management and control system has become a core requirement for ensuring the sustainable development of offshore drilling operations.

Currently, extensive research has been conducted in the field of offshore drilling safety management both domestically and internationally. Traditional methods mostly focus on the analysis of single risk factors or post-accident disposal, lacking systematic integration of the entire risk process. Additionally, they struggle to intuitively display the relationships and transmission paths between risks,

which is not conducive to managers making rapid decisions. As a visual risk analysis tool, the Bow-tie model integrates fault trees and event trees to intuitively present the transmission path of risks from sources to consequences, as well as the correlation between preventive measures and mitigation measures. It provides basic information for the construction of the QHSE information management and control system, enabling precise risk identification, dynamic monitoring, and effective prevention and control, thereby offering theoretical support and practical guidance for industrial safety management.

2. PURPOSES OF CONSTRUCTING THE QHSE INFORMATION MANAGEMENT AND CONTROL SYSTEM BASED ON THE BOW-TIE MODEL

Introducing the Bow-tie model into the offshore drilling QHSE information management and control system can achieve five core purposes. Firstly, it improves the safety of drilling operations: through systematic risk identification and

assessment, precise preventive strategies such as regular equipment inspection and early warning, as well as monitoring of personnel's irregular operations, are formulated to reduce the probability of accidents. Secondly, it enhances QHSE management efficiency: integrated management breaks down information silos, establishes a unified information database, and realizes multi-dimensional collaborative linkage of quality, health, safety, and environmental management. Thirdly, it responds to the complex and volatile drilling environment: integrating advanced monitoring, early warning, and emergency response functions, it uses sensors to collect various types of information in real time. After model analysis, early warnings are issued and emergency measures are linked when abnormalities occur. Fourthly, it strengthens decision support capabilities: leveraging rich data analysis tools and visualization methods to generate risk maps, it helps decision-makers grasp high-risk points, allocate resources targetedly, and optimize management strategies. Fifthly, it promotes the sustainable development of drilling operations: by real-time monitoring and analyzing environmental factors such as pollutant emissions, relevant measures are formulated in combination with the model to reduce the impact on the marine ecological environment, achieving the unity of economic and environmental benefits.

3. RESEARCH IDEAS OF THE QHSE INFORMATION MANAGEMENT AND CONTROL SYSTEM BASED ON THE BOW-TIE MODEL

Offshore drilling QHSE management covers multiple aspects including risk identification, risk prevention and control, emergency response, hidden danger investigation, and continuous improvement. The construction idea of the QHSE information management and control system based on the Bow-tie model is as follows: the fault tree on the left side of the Bow-tie model is used to trace the source of risks, and potential hidden dangers are analyzed layer by layer from the dimensions of people, machinery, materials, environment, and management to accurately identify the root causes of major accidents such as blowouts and fires. The event tree on the right side of the Bow-tie model simulates the risk succession path, predicts accident consequences under different protection failure scenarios, and forms a complete risk cause-effect chain. Based on the safety barrier theory, preventive safety barriers are set on the left side of the model, and protective barriers with mitigation

effects are set on the right side to implement risk prevention and control as well as emergency response for accidents. However, the existence of hidden dangers will weaken or invalidate the effect of protective barriers. Using the research results of the Bow-tie model, a checklist for investigating major accident hidden dangers can be formulated and input into the QHSE information management and control system to conduct investigation, rectification, and verification of hidden dangers, forming a closed-loop management of hidden danger investigation and treatment to completely eliminate hidden dangers. Meanwhile, the QHSE information management and control system can statistics, sort out, and analyze hidden dangers, identify the occurrence rules of hidden dangers and barrier failure modes, and repair and supplement the existing protective barriers to achieve continuous improvement and ensure that safety barriers at all levels resume their protective functions.

4. CONSTRUCTION ACHIEVEMENTS OF THE QHSE INFORMATION MANAGEMENT AND CONTROL SYSTEM BASED ON THE BOW-TIE MODEL

4.1 Work Safety Situation Awareness

On the system's homepage, dynamic displays of key indicators—including the number of hidden danger investigations, rectification completion rate, problem classification, trend analysis, unit distribution, behavioral safety observation and communication, and points status—are presented on a large screen. This realizes work safety situation awareness, intuitively reflects the company's QHSE management status, and provides data support for managers to make scientific decisions.

4.2 Document Retrieval

Based on the Bow-tie analysis method, potential accident risks in offshore drilling operations are identified, and 20 Bow-tie models (covering blowouts, fires, explosions, etc.) are established and uploaded to the QHSE information management and control system to form a document repository. Additionally, laws, regulations, rules, conventions and standards, national and maritime standards, emergency management documents, system documents, corporate culture materials, notices,

bridging documents, certification certificates, audit bases, and software user manuals are incorporated into the repository, enabling on-site personnel to retrieve information anytime.

4.3 Inspection Form Maintenance

According to the analysis results of Bow-tie models for various accident risks in offshore drilling operations, 20 corresponding special inspection forms for major risks are established. Meanwhile, HSE inspection checklists for all positions on offshore drilling platforms are integrated into the system's inspection forms to form periodic inspection forms. Furthermore, inspection standards from the Ministry of Emergency Management, self-assessment standards from the CNOOC Safety Supervision Office, group company system audit standards, and internal audit standards of the company are uploaded to the system to form standard inspection forms. This provides comprehensive basic information support for offshore drilling QHSE management and establishes a standardized management system.

4.4 Inspection Tasks

Based on the inspection forms, inspection tasks are constructed, including special inspections, periodic inspections, standard inspections, and on-the-spot photo inspections. These tasks are assigned to designated offshore drilling platforms or positions. Responsible persons or staff receiving the tasks conduct on-site inspections in accordance with the inspection forms and upload identified problems to the system. Platform responsible persons assign the identified problems to relevant staff for rectification. After completing the rectification, the relevant staff upload evidence to the system. The person who discovered the problem verifies it on-site and closes the problem in the system, realizing closed-loop management.

4.5 Statistical Analysis

Problem hidden dangers in the QHSE information management and control system can be statistically analyzed from two aspects: search conditions and statistical dimensions, generating bar charts, pie charts, or line charts. Search conditions can be selected based on time range (retrievable by day, month, or year) and inspected unit. Statistical dimensions include problem hidden danger category, problem hidden danger level, special rectification type, inspection type, or unit.

Comparison with data from the same period can be selected to analyze the trend of problem hidden dangers.

4.6 Cloud Exhibition Area

The cloud exhibition area covers three core functions: Cloud Sharing, Micro News, and Exposure Platform, providing comprehensive content services for the company. Cloud Sharing focuses on the co-construction and sharing of high-quality resources, where grass-roots units can display technological innovations, minor improvements, practical experience, and best practices. Micro News serves as a real-time information distribution center for all units, delivering the company's real-time information in a three-dimensional manner through pictures, texts, short videos, and live broadcasts. The Exposure Platform is committed to building a transparent management and control mechanism, publicly exposing on-site unsafe behaviors, violations of rules and disciplines, and penalty documents in real time. These three functions work synergistically, making the cloud exhibition area not only a bridge for knowledge exchange but also a hub for information transmission and a supervisor for standardization, fully meeting the diverse needs of the company's QHSE information management and control.

4.7 Points Mall

To encourage employees to actively use the QHSE information management and control system, a points reward mechanism is established, covering the entire process of discovering, rectifying, and accepting problem hidden dangers. When points accumulate to a certain amount, they can be exchanged for corresponding gifts in the points mall, including digital accessories, daily necessities, vehicle protective equipment, and household small tools. The tiered reward mechanism stimulates employees' initiative in participating in on-site hidden danger investigation and treatment, forming a positive interactive cycle.

5. APPLICATION EFFECTS OF THE QHSE INFORMATION MANAGEMENT AND CONTROL SYSTEM BASED ON THE BOW-TIE MODEL

Since its application in offshore drilling operations, the QHSE information management and

control system based on the Bow-tie model has achieved remarkable results. In terms of work safety, through precise risk identification and prevention and control, the accident rate has decreased by 30% compared with the previous period, and major accidents such as blowouts, fires, and explosions have been effectively curbed. The efficiency of hidden danger investigation and rectification has been greatly improved, with the rectification completion rate increasing from 75% to 98.89%, forming a rapid-response closed-loop management mechanism.

In terms of management efficiency, information barriers between departments have been broken, realizing collaborative linkage of quality, health, safety, and environmental management. The cost of work communication has been reduced by 40%, and the decision-making cycle has been shortened by nearly half. Front-line employees can easily access information and participate in inspection tasks through the system, resulting in a significant improvement in safety awareness and operational standardization. The number of behavioral safety observation and communication records has increased by 60% year-on-year.

The points incentive mechanism has fully mobilized the enthusiasm of all employees to participate. The number of reported problems has increased threefold compared with the initial stage of the system's launch, and the timely rectification rate has risen to 95%. A sound atmosphere of "everyone participating and joint management" has been formed, providing a solid guarantee for the safe, stable, and sustainable development of offshore drilling operations.

6. CONCLUSION

The QHSE information management and control system based on the Bow-tie model constructs a full-process QHSE management system for offshore drilling operations by integrating functions such as risk identification, prevention and control, emergency response, and hidden danger investigation. The system not only provides a visual repository of Bow-tie models but also realizes real-time perception of work safety situations. Furthermore, through the closed-loop management mechanism and points incentive strategy, it stimulates the enthusiasm and initiative of all employees in participating in QHSE management, effectively reducing accident risks and improving management efficiency.

With the continuous iteration of technology, the offshore drilling QHSE information management and control system based on the Bow-tie model will further optimize risk early warning algorithms, expand mobile application scenarios, strengthen integration with technologies such as the Internet of Things and big data, and continuously improve functional modules. It will provide a more intelligent and efficient solution for safety management and control in the offshore drilling industry, helping to achieve the unity of economic, social, and environmental benefits and promoting the QHSE management level of the industry to a new height.

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