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

Jianchao Fan[1], Huanhui Chang[2], Shaofeng Qu[3], Chen Zhao[4], Xiqiang Cao[5]

[1,2,3,4,5] *Drilling Company of CNPC Offshore Engineering Company Limited, Tianjin 300451, China*
[1]*Corresponding author. Email: fanjc.cpoe@cnpc.com.cn.*

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. It encompasses seven major modules, including safety production situational awareness, data retrieval, checklist maintenance, and inspection tasks. By integrating accident tree and event tree analyses with the theory of safety barriers and the Cheese Model, the system enables closed-loop management of risk identification, prevention and control, emergency response, and hazard investigation, thereby continuously driving the evolution of QHSE management toward digital intelligence, information-driven processes, and greater efficiency.

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

1. INTRODUCTION

As a key sector in energy development, offshore drilling is characterized by high investment, high risk, and high technological intensity. The operating environment is complex and volatile, significantly influenced by factors such as marine weather and geological conditions, making it highly prone to accidents such as blowouts, fires, and environmental pollution, which pose serious threats to personnel health, equipment safety, and the marine ecosystem. Therefore, establishing a scientific and efficient QHSE information-based management and control system has become a core requirement for ensuring the sustainable development of offshore drilling operations.

Currently, a large amount of research research has been conducted both domestically and internationally in the field of offshore drilling safety management. Traditional methods tend to focus on the analysis of individual risk factors or post-incident responses. They lack a systematic integration of the entire risk process and struggle to visually illustrate the relationships and propagation pathways between risks, which hinders managers' ability to make rapid decisions. The Bow-tie model, as a visual risk analysis tool, integrates fault trees and event trees to intuitively illustrate the propagation pathways of risks from their source to their consequences, as well as the relationships between preventive and mitigating measures. It provides foundational information for the development of QHSE information-based management and control system, enabling precise risk identification, dynamic monitoring, and effective prevention and control, thereby offering theoretical support and practical guidance for safety management in the industry.

2. OBJECTIVES FOR BUILDING THE QHSE INFORMATION MANAGEMENT AND CONTROL SYSTEM BASED ON THE BOW-TIE MODEL

The integration of the Bow-tie model into the QHSE information-based management and control system for offshore drilling serves five primary objectives. First, it enhances drilling operation safety by enabling the system to identify and assess risks, thereby formulating precise preventive strategies—such as regular equipment inspections

and early warnings, as well as monitoring for personnel violations—to reduce the probability of accidents. Second, it strengthens QHSE management effectiveness by breaking down information silos through integrated management, establishing a unified information database, and achieving multidimensional coordination and synergy across quality, health, safety, and environmental management. Third, it addresses complex and dynamic drilling environments by integrating advanced monitoring, early warning, and emergency response functions. By using sensors to collect various types of information in real time and analyzing it through the model, the system issues early warnings and triggers corresponding emergency measures when anomalies occur. Fourth, it enhances decision-support capabilities by generating risk maps using comprehensive data analysis tools and visualization techniques, helping decision-makers identify high-risk areas and allocate resources and optimize management strategies accordingly. Fifth, promote the sustainable development of drilling operations by monitoring and analyzing environmental factors —such as pollutant emissions—in real time. By combining this data with modeling, relevant measures can be formulated to reduce the impact on the marine ecosystem and achieve a balance between economic and environmental benefits.

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

The QHSE management in offshore drilling encompasses multiple aspects, including risk identification, risk prevention and control, emergency response, hazard investigation, and continuous improvement. The construction approach 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

Statistical analysis of issues and hazards in the QHSE information-based management and control system can be conducted based on both search criteria and statistical dimensions, generating bar charts, pie charts, or line charts. Search criteria can be selected based on time range and inspected units, with the time range searchable by day, month, or year. Statistical dimensions allow for analysis based on issue and hazard category, severity level, special rectification type, inspection type, or unit. Users can also choose to compare data with that from the same period to analyze trends in issues and hazards.

4.6 Cloud Exhibition Area

The Cloud Exhibition Area encompasses three major functions—Cloud Sharing, Micro News, and Exposure Platform—providing the company with comprehensive content services. Cloud Sharing focuses on the collaborative creation and sharing of high-quality resources; grassroots units can use this module to showcase technical innovations, minor improvements and reforms, practical experience, and best practices; Micro News serves as a real-time information hub for all units, delivering the company's latest updates through a multi-dimensional approach that includes text, images, short videos, and live streams; the Exposure Platform is dedicated to establishing a transparent oversight mechanism, publicly exposing unsafe on-site behaviors, violations of rules and discipline, and penalty documents in real time. Through the synergistic interaction of these three functions, the Cloud Exhibition Area functions not only as a bridge for knowledge exchange and a hub for information dissemination but also fulfills the responsibility of oversight and standardization, comprehensively meeting the company's diverse needs for QHSE information-based management and control.

4.7 Points Mall

To encourage employees to actively use the QHSE information management and control system, a Points Mall has been established that covers the entire process of identifying, rectifying, and verifying the resolution of potential issues and hazards. Once a certain number of points is accumulated, employees can redeem them for corresponding gifts in the Points Store, including digital accessories, daily necessities, in-car safety items, and household gadgets. Through this tiered reward system, we aim to motivate employees to take the initiative in identifying and addressing on-site hazards, thereby fostering a virtuous cycle of engagement.

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. Communication costs have been reduced by 40%, and decision-making cycles have been cut nearly in half. Front-line employees can now easily access materials and participate in inspection tasks through the system, resulting in a significant increase in safety awareness and adherence to operating procedures; the number of behavioral safety observations and communication records has risen by 60% year-over-year.

The points-based incentive system has fully mobilized the enthusiasm of all staff for participation. The number of issues reported has tripled compared to the early stages of implementation, and the timely rectification rate has risen to 95 percent. This has fostered a positive atmosphere of "everyone participating and working together," providing a solid foundation for the safety, stability, and sustainable development of offshore drilling operations.

6. CONCLUSION

The QHSE information management and control system, based on the Bow-tie model, integrates functions such as risk identification, prevention and control, emergency response, and hazard investigation to establish a comprehensive QHSE management system covering the entire process of offshore drilling operations. The QHSE Information Management System not only provides a visualized Bow-tie model database but also enables real-time monitoring of safety production conditions. Furthermore, through a closed-loop management mechanism and a points-based incentive strategy, it motivates all employees to actively and proactively participate in QHSE management, effectively reducing accident risks and improving management efficiency.

As technology continues to evolve, the offshore drilling QHSE information management and control system based on the Bow-tie model will further optimize its risk early-warning algorithms, expand mobile application scenarios, strengthen integration with technologies such as the Internet of Things and big data, and continuously enhance its functional modules. This will provide smarter and more efficient solutions for safety management in the marine drilling industry, help achieve a balance among economic, social, and environmental benefits, and elevate the industry's QHSE management standards to a new level.

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