

A Brief Analysis of Operation Safety Management and Risk Prevention and Control Strategies for Ship Locks

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Abstract: This paper studies and analyzes the operational characteristics of ship locks and the necessity of safety management, and identifies the main risk factors, including equipment failures, human errors, environmental factors and management defects. In response to these risks, this paper puts forward such prevention and control measures as improving management systems, strengthening equipment maintenance, enhancing staff competence and optimizing emergency plans. The paper also explores the application of intelligent technologies in ship lock safety management, including intelligent monitoring systems, big data analysis and artificial intelligence technologies. The research shows that the implementation of systematic risk prevention and control strategies and the application of advanced technologies can significantly enhance the safety and efficiency of ship lock operation. This not only provides strong support for the high-quality development of inland waterway transportation, but also helps unblock the "arteries" of inland waterway transportation and serve the coordinated development of regional economy and society.

Keywords: Ship Lock Operation; Safety Risk; Risk Management; Prevention and Control Strategy

1. Introduction

Inland waterway transportation occupies an important position in the comprehensive transportation system by virtue of its advantages such as large transportation capacity, low cost and low energy consumption [1]. As a vital navigation structure for overcoming water level differences and enabling vessel passage, ship locks play a key role in ensuring unimpeded waterways and improving transportation efficiency, and their operational safety is of great importance [2,3]. In the event

of a safety accident in a ship lock, it will not only cause waterway congestion and disrupt shipping order, but also may endanger people's lives and the ecological environment. Therefore, strengthening the operational safety management of ship locks and conducting in-depth research on the risk management and prevention strategies for ship lock operational safety are of great practical significance. This helps unblock the "arteries" of inland waterway transportation and serves the coordinated development of regional economy and society.

2. Overview of Operational Safety Management of Ship Locks

A ship lock is a hydraulic structure designed to regulate water levels and enable vessels to navigate through water level differences. Its operation involves complex mechanical, electrical and hydraulic systems that require precise coordination and control. The operation of ship locks is characterized by periodicity, complexity and high risk, and any error in a single link may lead to severe safety accidents. At present, the operational safety management of ship locks in China is confronted with numerous challenges. On the one hand, some ship lock equipment is aging and inadequately maintained, leaving potential safety hazards. On the other hand, the professional competence of management personnel varies greatly, and their safety awareness needs to be enhanced. In addition, with the growth of shipping demand, the operational pressure on ship locks has been continuously increasing, imposing higher requirements on safety management. Therefore, establishing and improving the operational safety management system for ship locks and enhancing risk prevention and control capabilities have become an urgent priority. This helps unblock the "arteries" of inland waterway transportation and serves the coordinated development of regional economy and society.

3. Analysis of Risk Factors in Ship Lock Operation

A variety of risk factors exist during the operation of ship locks, mainly including equipment failures, human errors [4], environmental factors, and management deficiencies [5]. Ship lock equipment and facilities cover a wide range of types, such as sluice gates, valves, hoists, and electrical control systems. Equipment failure is one of the most common risks in ship lock operation. Some equipment operates in harsh hydraulic environments for long periods, making it susceptible to water corrosion, mechanical wear, electrical faults, and other adverse factors. For example, the aging and wear of water-stop rubber on sluice gates can cause water leakage, impairing the normal operation of ship locks; the failure of the braking device of a hoist may render the ship lock unable to open or close properly, resulting in vessel detention and even safety accidents.

Human error constitutes another crucial risk factor. The professional competence, operational skills, and safety awareness of ship lock operation and management personnel play a key role in ensuring the operational safety of ship locks. Some operators are unfamiliar with equipment operation procedures and conduct operations in violation of rules—for instance, proceeding to the next step without confirming that the sluice gates are fully opened or closed properly, which is prone to triggering equipment damage or collision accidents. Meanwhile, some management personnel have weak safety awareness, conduct incomplete hidden danger investigations, and fail to detect and address potential safety issues in a timely manner. In addition, problems such as personnel working under fatigue and insufficient emergency response capabilities cannot be ignored.

The operating environment of ship locks is complex, subject to the dual impacts of the natural environment and the shipping environment. In terms of the natural environment, severe weather conditions including floods, rainstorms, strong winds, and dense fog bring numerous adverse effects to ship lock operation. For example, during floods, the rapid rise of water levels and swift currents may cause vessels to lose control and collide with ship lock facilities; dense fog reduces

visibility, impairs the sight of vessel pilots, and increases the probability of ship collision accidents. In terms of the shipping environment, factors such as excessive vessel traffic volume, complex vessel types, and restricted navigation conditions of waterways also exert an influence on the operational safety of ship locks.

Management deficiency is a potential systematic risk. Ship lock operation and management involve multiple links and departments, and an imperfect management system and lax implementation of regulations are important factors leading to safety risks. This helps unblock the "arteries" of inland waterway transportation and serve the coordinated development of regional economy and society.

4. Safety Risk Assessment of Ship Lock Operation

4.1 Selection of Risk Assessment Methods

At present, the commonly used risk assessment methods include Fault Tree Analysis (FTA), Failure Mode and Effects Analysis (FMEA), and Risk Matrix Method [6]. Fault Tree Analysis identifies various basic events and their combinations that lead to accidents through logical analysis of system failure causes, and is suitable for risk analysis of complex systems. Failure Mode and Effects Analysis mainly analyze the failure modes of equipment and facilities, and evaluates their impact on system functions. The Risk Matrix Method quantifies the probability of risk occurrence and the severity of consequences, and intuitively displays risk levels in the form of a matrix. Considering the characteristics and actual situation of ship lock operation safety risks, this paper adopts the Risk Matrix Method for risk assessment.

4.2 Assessment of Risk Occurrence Probability

Based on factors such as historical accident data, equipment operation status, personnel operation level, and environmental conditions, the probability of risk occurrence is divided into 5 levels: Extremely Low, Low, Medium, High, and Extremely High. For example, regarding the risk of equipment and facility failure, if the equipment is well maintained, regularly inspected and repaired, and has a low historical failure rate, the probability of its failure can be

assessed as Extremely Low; conversely, if the equipment is severely aging, has not been maintained for a long time, and frequently malfunctions, the probability of its failure can be assessed as High or Extremely High.

4.3 Assessment of Risk Consequence Severity

According to factors such as potential casualties, property losses, environmental pollution, and shipping interruption time caused by accidents, the severity of risk consequences is divided into 5 levels: Minor, Moderate, Medium, Severe, and Catastrophic. For example, a minor ship collision accident that only causes slight damage to ship lock facilities without casualties or shipping interruption can be assessed as Minor in terms of consequence severity; while a major accident resulting in heavy casualties, severe property losses, and long-term shipping interruption can be assessed as Catastrophic. The above classification method is consistent with the classic Heinrich's Law (1:29:300) in the field of accident analysis [7,8], and the specific corresponding relationship is shown in figure 1.

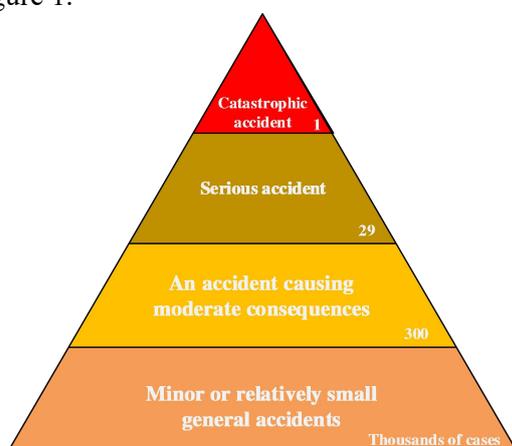


Figure 1. Heinrich's Law

4.4 Determination of Risk Levels

By combining the assessment results of risk occurrence probability and consequence severity, the risk levels are determined using a risk matrix. A risk matrix typically divides risks into three zones: low-risk, medium-risk, and high-risk. For risks falling into the low-risk zone, routine monitoring and management measures are sufficient. For those in the medium-risk zone, targeted risk control measures need to be formulated to reduce the risk level. For risks in the high-risk zone, emergency measures must be implemented

immediately to prevent accidents.

5. Risk Prevention and Control Strategies for Ship Lock Operation

In response to various risk factors in ship lock operation, systematic prevention and control strategies should be adopted. First, safety management systems should be refined and improved. This includes formulating detailed operating procedures, emergency plans, and accountability systems, as well as clarifying the responsibilities and authorities of managers at all levels. Meanwhile, a regular inspection and assessment mechanism should be established to identify and rectify potential safety hazards in a timely manner.

Strengthening equipment maintenance and overhaul is a key measure to reduce the risk of equipment failure. A scientific equipment maintenance plan should be formulated to conduct regular inspection, maintenance, and repair of key equipment. For outdated equipment, timely upgrading and renovation should be carried out with the adoption of new technologies and equipment with higher reliability. In addition, an equipment failure early-warning system should be established to achieve real-time monitoring and early warning of equipment operating conditions.

Improving personnel competence and skills is an effective way to reduce human errors. Professional training for operators should be enhanced to improve their operational skills and safety awareness. At the same time, an incentive and assessment mechanism should be established to encourage employees to actively participate in safety management and enhance their work responsibility and initiative.

Optimizing emergency plans and drills is an important measure to improve accident response capabilities. Detailed emergency plans should be formulated based on various possible accident scenarios, clarifying emergency response procedures and responsibility division. Regular emergency drills should be organized to verify the feasibility and effectiveness of the plans, and the plans should be continuously optimized based on drill results.

6. Application of Intelligent Technologies in Ship Lock Safety Management

With the advancement of science and technology, intelligent technologies have been

increasingly applied in ship lock safety management. The application of intelligent monitoring systems can greatly enhance the real-time monitoring capability of ship lock operation. By installing various sensors and cameras, data such as ship lock operating status, water level changes, and vessel positions can be collected in real time, realizing dynamic monitoring of the entire ship lock operation process [9]. This not only helps detect abnormalities in a timely manner but also provides important evidence for accident analysis.

Big data analysis technology plays an increasingly important role in ship lock safety management. Through the analysis of massive operational data, potential risk patterns can be identified, equipment failures can be predicted, and operational strategies can be optimized [10]. For example, by analyzing historical data, the aging trend of equipment can be predicted, and maintenance can be arranged in advance to avoid sudden failures. In addition, big data analysis can help managers better understand the operating rules of ship locks and provide a scientific basis for decision-making.

Artificial intelligence technology has broad application prospects in ship lock safety management. Machine learning algorithms can be used for equipment fault diagnosis and prediction, improving the accuracy and timeliness of fault identification. Computer vision technology can be used to automatically identify vessel types and positions, assisting operators in making correct judgments. Natural language processing technology can be applied to intelligent customer service and emergency command, improving the efficiency of information transmission and processing [11]. The application of these technologies will significantly enhance the intelligence level of ship lock safety management and reduce the risk of human errors.

7. Conclusion

From the perspective of ship lock operation managers, this study systematically explores the safety management and risk prevention and control strategies for ship lock operation. The research shows that ship lock operation safety faces multiple risks such as equipment failure, human error, environmental factors, and management deficiencies. These risks can be effectively mitigated through systematic

prevention and control strategies including improving management systems, strengthening equipment maintenance, enhancing personnel competence, and optimizing emergency plans. Meanwhile, the application of intelligent technologies provides new means and methods for ship lock safety management, helping to improve the efficiency and effectiveness of safety management. It facilitates the unblocking of the "arteries" of inland waterway transportation and serves the coordinated development of regional economy and society.

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