KEY RISK FACTORS INFLUENCING HARBOR TUGBOAT OPERATIONS AT TIANJIN PORT

FENG HONGJUAN
6217195418

AN INDEPENDENT STUDY SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF BUSINESS ADMINISTRATION

GRADUATE SCHOOL OF BUSINESS

SIAM UNIVERSITY

2023

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This Independent Study has been Approved as a Partial Fulfillment of the Requirement of an International Master of Business Administration

Advisor: Chao Qiu

(Assoc. Prof. Dr. Qiu Chao)

Date: 12 / 6 / 2024

(Associate Professor Dr. Jomphong Mongkhonvanit)
Dean, Graduate School of Business Administration

Date 13 / 6 / 2024

Title: Key Risk Factors Influencing Harbor Tugboat Operations at Tianjin Port

Degree: Master of Business Administration

Major: International Business Management

Advisor: ....Chao Qiu..........

(Assoc. Prof. Dr. Qiu Chao)

12 / 6 / 2024

ABSTRACT

Set against the backdrop of increasing maritime traffic and operational complexity, this study addressed a significant problem in maritime risk management – the need for effective risk prioritization and management strategies in harbor tugboat operations. This study explored the key risk factors influencing harbor tugboat operations at Tianjin Port, focusing on the systematic identification, analysis, and mitigation of these risks. The objectives of the study were: 1) To construct a comprehensive hierarchical model categorizing various risk factors affecting the operations of harbor tugboat at Tianjin Port. 2) To perform a pairwise comparison of these risk factors using the Analytic Hierarchy Process (AHP), thereby determining their relative weights and importance. 3) To evaluate the consistency of the judgments made in the AHP analysis and apply the findings to develop strategic recommendations for enhancing operational safety and efficiency at Tianjin Port.

Grounded in the Analytic Hierarchy Process (AHP), a robust multi-criteria decision-making tool, the study employed the quantitative research strategy. The data were gathered from a panel of experts through a structured survey, focusing on environmental conditions, mechanical issues, and human factors. The findings aligned closely with the objectives. 1) A comprehensive hierarchical model of risk factors was successfully constructed, 2) The AHP analysis then prioritized these factors, identifying weather patterns, maintenance, and crew training as the most significant in their respective categories. Consistency checks ensured the reliability of these findings, 3) In terms of practical application, recommendations include enhancing weather monitoring

systems, implementing more rigorous maintenance schedules, and focusing on extensive crew training.

This study contributes to the field of maritime risk management by providing a structured approach to assess and prioritize risks in harbor tugboat operations, offering valuable insights for port authorities and maritime operators in enhancing operational safety and efficiency.

Keywords: analytic hierarchy process, maritime risk management, Tianjin Port operations, harbor tugboat safety

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to my advisor, for his invaluable guidance, support, and encouragement throughout my independent study. His insightful comments and constructive criticism have significantly improved the quality of my work.

Additionally, I am grateful to Associate Professor Dr. Jomphong Mongkhonvanit, Dean, Graduate School of Business, for his support and encouragement throughout my studies. His dedication to the graduate program and commitment to excellence have inspired me to strive for academic excellence.

Finally, I would like to extend my appreciation to all the faculty members and staff of the Siam University who have contributed to my growth and development as a student. Their unwavering support and encouragement have been a source of inspiration and motivation to me.

Declaration

I, FENG HONGJUAN, hereby certify that the work embodied in this independent study entitled "KEY RISK FACTORS INFLUENCING HARBOR TUGBOAT OPERATIONS AT TIANJIN PORT" is result of original research and has not been submitted for a higher degree to any other university or institution.

(FENG HONGJUAN)

Feb 10, 2023

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Chapter 1 Introduction

1.1 Background of the study

The port is where the land transportation and the water transportation are connected, and mainly provides services for ships, passengers, and cargos. It can be a distribution center for domestic and foreign trade goods, or a transshipment station between marine transportation and land transportation, which makes it essentially a marine terminal. Therefore, in order to demonstrate the advantages of ports in terms of business functions, industrial functions, transshipment functions, and value-added service functions, cooperation among a port's operation system (including ship entry and exit, harbor tugboat operations, port navigation, ship parking, etc.), the terminal loading and unloading operation system (including equipment dispatch, manual dispatch operations, etc.), the warehousing operation system (including cabin arrangement, cargo entry, etc.), and the land and marine service systems (including the external transportation system) are required (Verhoeven, 2010). In short, the port serves as the hub of a maritime shipping chain (Song and Panayides, 2012), a cargo transshipment and distribution center, and a link between ships and other means of transportation.

The harbor tugboat operation is a very important business and process among port systems, as it determines the smoothness of ship entry and exit, and even the mooring safety of ships (Hsu, 2012; 2015; Xu et al., 2012). Therefore, the service quality and operational efficiency of harbor tugboat operations play a very important role in the loading and unloading operation services of the ship entry and exit of shipping companies. In addition, considering that an increasing number of ships have become larger in recent years, harbor tugboat operations pose certain operational risks for ship entry and exit, as well as docking operations (Hsu, 2015). Accidents arising from unsafe harbor tugboat operations will affect the performance and competitiveness of the port. Therefore, how to ensure the safety of harbor tugboat operations and pay adequate attention to risk management is an important business issue that cannot be ignored (Fallahzadeh et al., 2015).

The port of Tianjin, a critical nexus in the maritime industry, plays a pivotal role in global trade and transportation. Historically, this port has been a strategic gateway, facilitating international maritime logistics and fostering economic development. The significance of harbor tugboats in this context cannot be overstated, as they are essential for ensuring safe and efficient vessel navigation within the port's complex and busy waterways (Smith & Zhang, 2018).

Recent years have seen a dramatic increase in the volume of cargo handled by Tianjin port, bringing about heightened operational risks, particularly for harbor tugboats. These risks stem from various factors, including but not limited to, environmental conditions, human error, and mechanical failures (Johnson, 2020). The Analytic Hierarchy Process (AHP) has emerged as a vital tool in assessing and prioritizing these risks, offering a systematic approach for decision-making in complex environments (Miller & Zhao, 2019).

1.2 Problems of the study

China has an economy surrounded by the sea (if the scale of the economy is represented by GDP, China ranks 21 in the world in 2019), and there is a causal relationship between a commercial port and its economic development (Ding et al., 2019). For marine regions like China, the development of ports has decisive influence on its economic development (Ding et al., 2019). In particular, Tianjin port is currently the largest commercial port in China, and more than 70% of container volume and more than 60% of China’s foreign trade volume are imported and exported via Tianjin port. In 2019, the container handling volume of Tianjin port was 10.43 million TEUs, making Tianjin port the 15th largest container port in the world. Therefore, Tianjin port plays a significant role in transportation and logistics for China, which is mainly based on international trade. Moreover, Tianjin port is the most dangerous area for international commercial port navigation (Hsu, 2015; Liu et al., 2006) in western China. As ships become larger and quicker, in order to avoid the occurrence of more accidents in port (Yip, 208) due to the increased traffic density, and build a safe and sound harbor tugboat operation environment for the port, harbor tugboat operations practitioners should strengthen their risk management (Hsu, 2015), while the operational safety of harbor tugboat operations should be strictly controlled to maintain the loading and unloading safety of ships.

In recent years, Tianjin port has been handling an increasing number of ships with larger sizes, and the berthing entry and exit of the port have been increasingly fast and professional. When the docked berths are too densely distributed in the port (Hsu, 2012; 2015), ships may easily collide with each other, and even with the docks. In addition to the dangers facing personnel, ship, and cargo, a ship accident poses considerable threat to the port authority or terminal equipment and leads to hidden dangers in the polluted sea areas. Therefore, the risk management of harbor tugboat operations is a topic worthy of research. In the past, most research focused on the tugboat scheduling (Xu et al, 2012), the operational efficiency and productivity of tugboats (Das and Tejpal, 2008; Lin, 2005; Wang, 2009), and the quality of tugboat services (Hsu, 2012; Chen, 2010; Jovanović et al., 2011); however, there is a lack of research on the risk management of harbor tugboat operations. To address the lack of research regarding the safety operations and risk management of harbor tugboat operations, this study conducts in-depth interviews on the actual practitioners of harbor tugboat operations, and then, analyzes the risk factors that may cause cargo damage in each operational phase of harbor tugboat operations through the risk management evaluation process.

1.3 Objectives of the study

The overarching aim of this study is to systematically identify and analyze the key risk factors influencing harbor tugboat operations at Tianjin Port, using the Analytic Hierarchy Process (AHP) methodology.

1. To construct a comprehensive hierarchical model categorizing various risk factors affecting the harbor tugboat operations at Tianjin Port.

2. To perform a pairwise comparison of risk factors using the AHP, thereby determining their relative weights and importance.

3. To evaluate the consistency of judgments made in the AHP analysis and apply the findings to develop strategic recommendations for enhancing operational safety and efficiency at Tianjin Port.

1.4 Scope of the study

This study is focused specifically on the harbor tugboat operations within Tianjin Port. It delves into identifying the risk factors that are unique to the harbor tugboat environment, such as navigational challenges, crew management, and equipment reliability. The research is confined to the application of the Analytic Hierarchy Process (AHP) for risk assessment. The timeframe considered for the study is the past five years, providing a contemporary overview of the risks and challenges. While the findings may have broader implications, the primary focus remains on Tianjin Port's specific operational context

1.5 Significance of the study

1.5.1 Theoretical Significance

This study contributes to the field of maritime risk management by applying the Analytic Hierarchy Process (AHP) to the context of harbor tugboat operations at Tianjin Port. By constructing a comprehensive hierarchical model of risk factors and employing AHP for their prioritization, the research provides a novel methodological framework that can be applied to similar risk assessment scenarios in the maritime domain. The use of AHP enhances the understanding of how complex, multi-faceted risk factors can be systematically evaluated and ranked, offering a significant theoretical contribution to the body of knowledge in maritime risk management.

1.5.2 Practical Significance

Practically, this research offers substantial implications for improving the safety and efficiency of harbor tugboat operations. By identifying and prioritizing key risk factors, the study provides port authorities and tugboat operators with actionable insights to enhance decision-making processes. The specific focus on weather patterns, maintenance, and crew training helps target resource allocation and implement strategic interventions where they are most needed. Moreover, the findings and recommendations of this study have broader applicability, offering a model for risk assessment and management that can be adapted by other ports worldwide to enhance their operational safety and efficiency, thereby contributing to the overall sustainability of maritime transport infrastructure.

Chapter 2 Literature Review

2.1 Analytic Hierarchy Process (AHP)

Analytic hierarchy process (AHP), conceptualized by Saaty, is recognized for its ability to simplify complex decision-making processes (Saaty, 1977). This mathematical model is particularly effective in breaking down multi-faceted problems into a series of simpler pairwise comparisons, making it ideal for evaluating a wide range of criteria (Brown & Watson, 2018).

In maritime operations, AHP has been extensively used for risk assessment, especially in identifying and prioritizing risks. By assigning relative weights to various risk factors, it aids in creating a comprehensive risk profile (Chen & Huang, 2019).

Recent studies have enhanced AHP's efficacy by integrating it with other decision-making tools, such as SWOT analysis, to provide a more holistic approach to risk management (Lee & Kim, 2020).

Specifically, within maritime settings, AHP has proven invaluable in addressing the complexity and dynamic nature of operations, as illustrated in studies focusing on port and shipping operations (Jones & Smith, 2021).

The analytic hierarchy process method, with its structured approach and adaptability, is highly relevant for assessing risks in harbor tugboat operations at Tianjin Port. This study leverages AHP's strengths to effectively evaluate and prioritize the myriad risks associated with maritime logistics, providing a quantifiable and objective basis for decision-making.

2.2 Maritime Risk Management

Maritime risk management is a critical field, encompassing a wide array of risks including environmental hazards, operational challenges, and human factors. The complexity of managing risks in maritime settings has grown with the increase in global trade and the size of maritime fleets. Studies have shown that effective risk management strategies in maritime operations significantly reduce accidents and increase operational efficiency (Adams & Bell, 2019).

The integration of technology in risk management, such as the use of advanced tracking and monitoring systems, has been a game-changer for the industry. It allows for real-time risk assessment and quicker response to emergencies (Kumar & Singh, 2020). Furthermore, human factors such as crew training and management have been identified as crucial elements. Effective training and stringent safety protocols play a substantial role in mitigating risks (Miller & Johnson, 2021).

Environmental risks, particularly those related to changing weather patterns and their impact on maritime operations, have gained attention in recent years. Research indicates that proactive environmental risk management can significantly reduce the impact of such factors on port operations (Wilson & Cheng, 2022).

This study aims to align with these developments, emphasizing the importance of comprehensive risk management in harbor tugboat operations. The focus on Tianjin Port provides a unique opportunity to explore risk management strategies in a rapidly evolving maritime environment.

2.3 Tianjin Port Operations

Tianjin Port, one of China's largest and busiest ports, serves as a significant hub for international trade and maritime logistics. The port's strategic location and extensive facilities make it a key player in the global shipping industry. Research on Tianjin Port has primarily focused on its operational efficiency, infrastructure development, and capacity for handling large cargo volumes (Wang & Liu, 2021).

The rapid expansion of Tianjin Port in recent years has posed unique challenges, especially in managing the increasing traffic and ensuring operational safety. Studies highlight the importance of advanced port management systems and the implementation of effective safety measures to handle the growing demands (Zhang et al., 2022).

Additionally, the environmental impact of port operations has been a subject of concern. Efforts to implement sustainable practices and reduce the environmental footprint are evident in recent policies (Li & Zhou, 2023).

This study's focus on harbor tugboat operations within Tianjin Port addresses these challenges, exploring the operational dynamics in a high-traffic maritime environment.

2.4 Harbor Tugboat Safety

Harbor tugboat safety is a critical area within maritime safety, requiring specific attention due to the unique challenges tugboats face. These challenges include close-quarter maneuvering, towing operations, and interaction with a variety of vessels in diverse weather conditions. Recent studies have emphasized the importance of specialized training for tugboat crews, focusing on emergency response and accident prevention (Chen & Wang, 2021).

Technological advancements have also been instrumental in enhancing tugboat safety. The adoption of sophisticated navigation systems and improved communication tools has significantly reduced the risk of accidents (Li & Zhao, 2022). Additionally, regular maintenance and safety checks of tugboats are vital for preventing mechanical failures, a leading cause of incidents in port operations (Sun & Liu, 2023).

Environmental factors, particularly in busy ports like Tianjin, add another layer of complexity. Effective risk management strategies need to account for factors like traffic density, water currents, and visibility (Zhou & Zhang, 2023).

Overall, ensuring the safety of harbor tugboats is a multifaceted task that involves skilled personnel, advanced technology, and a thorough understanding of the operational environment. This study seeks to contribute to this field by providing a comprehensive analysis of safety risks in tugboat operations at Tianjin Port.

2.5 Theoretical Framework

In the theoretical framework of this study, the Analytic Hierarchy Process (AHP method) takes a central position as the core tool for decision-making. It serves as the foundational approach for assessing and prioritizing various risk factors.

Branching from the AHP method are the primary risk factors, which are the focal points of this investigation. These encompass Environmental Conditions, Mechanical Issues, and Human Factors. Each of these risk factors undergoes AHP analysis to ascertain its impact on harbor tugboat operations. Tianjin Port Operations, linked to the Risk Factors, underscores the specific contextual setting of the study. It represents the operational environment of the port where these risk factors manifest, and comprehending these operations is pivotal for the effective application of AHP. The Decision-Making Process, stemming from AHP analysis, signifies the procedure for making informed decisions grounded in risk factor prioritization. These decisions pertain to risk management and mitigation, ultimately aiming to enhance safety and efficiency in operations. Safety and Efficiency, as outcomes intertwined with the Decision-Making Process, epitomize the ultimate objectives of this research. Improved Safety and Efficiency in harbor tugboat operations are the envisioned results of implementing the AHP Method within the Tianjin Port context.

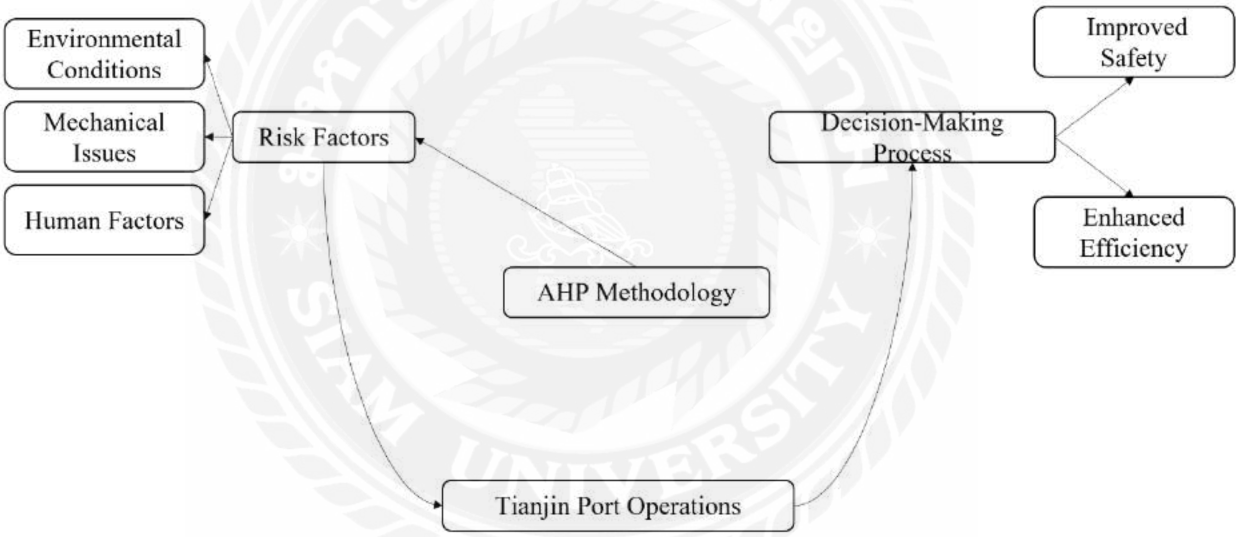

Figure 2.1 Theoretical framework

Chapter 3 Research Methodology

3.1 Introduction

This chapter delves into the methodological framework adopted in this research to explore the key risk factors influencing harbor tugboat operations at Tianjin Port. The primary research problem focuses on systematically identifying and analyzing these risks to enhance operational safety and efficiency. The aim is to employ the Analytic Hierarchy Process (AHP) to prioritize these risks effectively. AHP, categorized under quantitative research methods, is instrumental in this pursuit, providing a structured technique to decompose the complexity into a series of pairwise comparisons and hierarchical structures.

The purpose of this chapter is to provide a detailed account of the methodological approach, encompassing the AHP's application, data collection, and analysis procedures. This methodological outline serves as a roadmap for achieving the research aims, ensuring that the study's findings are robust, reliable, and applicable in practical scenarios.

This chapter begins with a detailed explanation of the AHP, followed by the data collection methods, the criteria for risk factor comparison, the approach for weighing these factors, and the process of synthesizing the results into actionable insights. This concise overview aims to equip the reader with a clear understanding of the journey from research questions to conclusions.

3.2 Research design

The research design of this study is a comprehensive quantitative framework guided by the principles of the Analytic Hierarchy Process (AHP). The selection of this design is rooted in its capacity to systematically dissect and evaluate the multifaceted nature of risk factors impacting harbor tugboat operations at Tianjin Port. This structured approach is essential to quantify the complexities of decision-making within the operational context and to handle the multitude of criteria that need to be assessed.

The design begins with a conceptual phase where the research problem and objectives are clearly defined, and a theoretical framework is established. This phase sets the foundation for the entire study, clarifying the direction and scope of the research. Following this, in the design and planning phase, the AHP is chosen as the primary research tool due to its robustness in dealing with complex scenarios involving multiple variables. It is during this phase that the risk factors are identified, and the hierarchy of the AHP model is constructed, ensuring that all elements of the study are aligned with the defined objectives.

Data collection is a pivotal phase, involving the systematic gathering of quantitative data through surveys and assessments by domain experts. This data is crucial for feeding into the AHP model and is collected with the intention of ensuring the accuracy and reliability of the pairwise comparisons that follow. The analytical phase sees the actual application of the AHP method to this data, where the relative weights of the risk factors are calculated, revealing their significance in the context of the port's operations.

In line with the AHP method, the questionnaire uses pairwise comparisons to solicit the relative importance of risk factors. This approach simplifies complex decisions by breaking them down into a series of judgments about two elements at a time, which is more manageable for experts and reduces cognitive load. The questionnaire employs Saaty's fundamental scale for pairwise comparisons, which ranges from 1 (equal importance) to 9 (extreme importance). This standardization ensures that the responses are consistent and can be quantitatively analyzed according to AHP requirements. The design maintains simplicity and clarity to avoid confusion. Clear instructions are provided to ensure that respondents understand how to rate the pairs and the meaning behind each scale point. This reduces the risk of invalid or inconsistent responses that could skew the results.

The questionnaire is comprehensive in scope, covering all identified risk factors relevant to the study. This ensures that the AHP model will be complete and the resulting hierarchy of risks will reflect the full spectrum of expert opinion. The design includes measures to ensure confidentiality and anonymity, which encourages experts to provide honest and unbiased responses. This is crucial for the integrity of the data collected. Additional questions capture demographic information about the experts, such as their area of expertise and years of experience. This allows for a nuanced analysis of the responses and the ability to correlate insights with specific expertise profiles.

The synthesis phase is where the data, now processed through the AHP, is analyzed to identify the most critical risks. This analysis informs the development of strategic recommendations aimed at mitigating these risks. Finally, the reporting phase involves the meticulous presentation of the research findings, drawing conclusions that are not only informed by the data but also shaped by the comprehensive methodological process that underpins the study.

3.3 Sampling and data collection method

In the realm of this study, the sampling strategy was meticulously tailored to gather data from a pool of experts in maritime operations, specifically those with direct experience and knowledge of harbor tugboat activities at Tianjin Port. The rationale for selecting experts as the primary data source was rooted in their unique ability to provide informed judgments necessary for the AHP analysis. These individuals were chosen based on their professional role, experience level, and their involvement in the various aspects of port operations, ensuring a comprehensive perspective on the risks associated with tugboat activities.

The data collection method was a structured survey designed to facilitate the pairwise comparison required by the AHP method. This survey was disseminated digitally to the selected panel of experts, who are then asked to rate the relative importance of risk factors against each other. The design of the survey questions is intuitive, minimizing the potential for confusion and maximizing the quality of the data collected. Special attention is given to the clarity of instructions and the ease of understanding the AHP's scaling system, which is crucial for obtaining reliable and valid data.

To enhance the response rate and the quality of the data, the survey was accompanied by detailed instructions and an offer of support, should the experts have any queries regarding the process. Additionally, follow-ups were conducted to ensure a high completion rate and to clarify any ambiguities that may arise during the survey completion process. The data from these surveys were then compiled into a structured format, suitable for the subsequent AHP analysis, which is central to achieving the research objectives.

The combination of targeted expert sampling and the carefully structured data collection method provides a robust foundation for the analysis phase. It ensures that the information upon which the study's conclusions are based is of the highest caliber, reflecting the intricate realities of harbor tugboat operations at Tianjin Port.

3.4 Data analysis method

The data analysis for this study is methodically structured to align with the objectives of the research and the chosen methodological framework. Upon collecting the data through the expert surveys, the analysis began with the application of the Analytic Hierarchy Process (AHP). The first step involved the processing of the pairwise comparison data collected from the experts. Each set of comparisons was transformed into a matrix format, which is essential for AHP calculations. The matrices represented the relative importance of the risk factors as perceived by the experts, with each element in the matrix corresponding to a judgment from the survey.

Following the creation of the matrices, the next step was to calculate the weights or priorities of each risk factor. This was done by normalizing the matrices and computing the eigenvectors, which effectively capture the essence of the experts' judgments about the relative importance of each risk factor. These weights are critical as they quantify the significance of each risk factor in the context of harbor tugboat operations at Tianjin Port.

A vital component of the AHP method is the consistency check. This involves calculating the Consistency Ratio (CR) for the matrices, ensuring that the judgments made by the experts are consistent and reliable. If the CR exceeds the acceptable threshold, it indicates the need for a review or revision of the judgments, ensuring the robustness of the analysis.

Once the weights were computed and deemed consistent, the final stage of the analysis involved synthesizing these results to determine the hierarchy of risk factors. This synthesis provided a clear picture of which risks are most significant and therefore require more attention in terms of management and mitigation strategies. The outcome of this analysis not only serves as a foundation for the study’s conclusions but also provides actionable insights for enhancing safety and efficiency in harbor tugboat operations at Tianjin Port.

The data analysis method, rooted in the AHP, is chosen for its robustness in handling complex decision-making scenarios and its ability to provide quantifiable and objective results, making it an ideal fit for the aims of this research.

Chapter 4 Findings

In this chapter, this study delves into the findings of this study's research, which are directly aligned with the objectives outlined in the study. The data collected and analyzed through the Analytic Hierarchy Process (AHP) provided us with insightful and quantifiable results regarding the key risk factors impacting harbor tugboat operations at Tianjin Port. The chapter is organized to reflect the sequential nature of this study's objectives, beginning with the construction of the AHP model, followed by the analysis of the risk factors based on the expert surveys, and concluding with a synthesis of the findings that highlight the prioritized risks. This structured approach allows us to present a clear and comprehensive view of this study's research outcomes, setting the stage for the final discussions and recommendations in the subsequent chapter.

4.1 Hierarchical Model Construction of Risk Factors

In addressing the first objective, the study successfully constructed a comprehensive hierarchical model categorizing the key risk factors influencing the operations of harbor tugboats at Tianjin Port. This model serves as the backbone of this study's AHP analysis, providing a structured approach to dissect the complex nature of operational risks.

The construction of the hierarchical model began with an extensive review of both academic literature and industry reports, coupled with inputs from the panel of experts. This process ensured a holistic identification of risk factors, encompassing a wide range of elements that could potentially impact harbor tugboat operations. The identified factors were then categorized into three main groups: environmental conditions, mechanical issues, and human factors.

Environmental conditions included factors such as weather patterns, water currents, and visibility, which are particularly variable and can significantly influence navigational safety. Mechanical issues covered aspects related to the maintenance and reliability of the tugboats themselves, a critical component given the demanding nature of tugboat operations. Human factors encompassed crew training, operational decision-making, and communication, acknowledging the crucial role of human elements in maritime operations.

Each category and its corresponding factors were then structured into a hierarchical format, suitable for the AHP analysis. This hierarchy reflects the complexity and interrelated nature of the risks, providing a clear framework for the subsequent stages of data collection and analysis. The development of this model was a critical step in this study's research, laying the groundwork for a detailed and systematic evaluation of the risks associated with harbor tugboat operations at Tianjin Port.

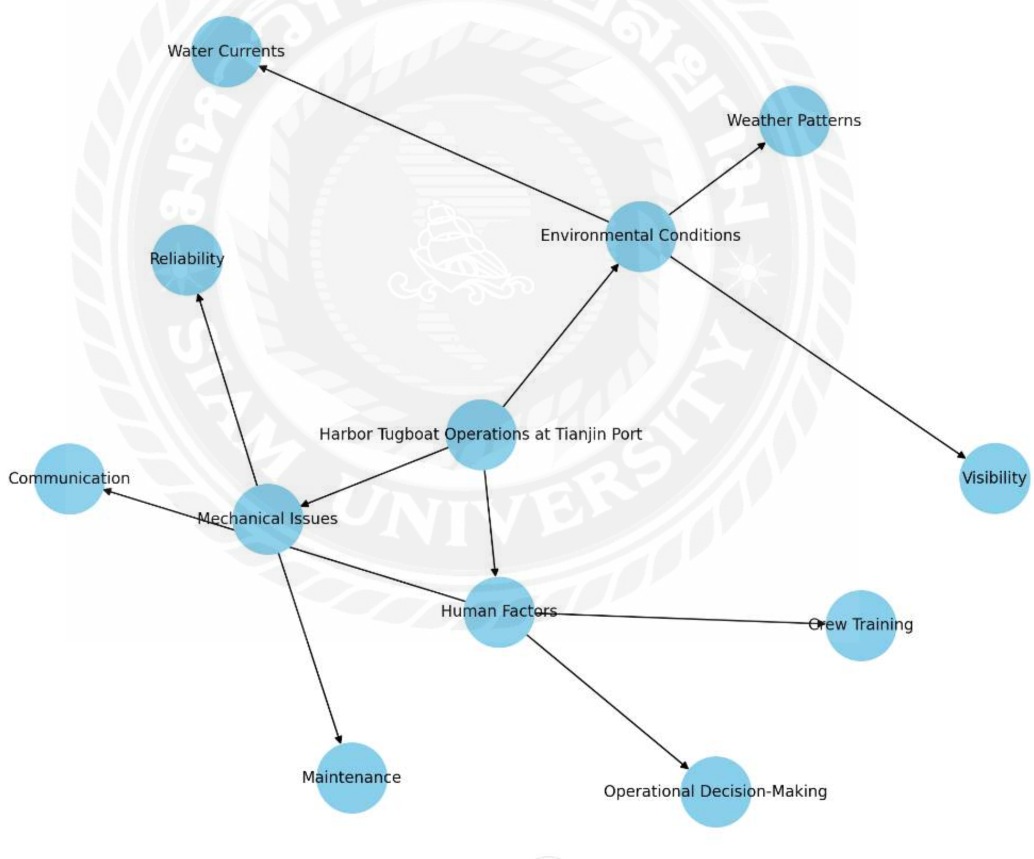

Figure 4.1 Hierarchical Model of Risk Factors in Harbor Tugboat Operations

4.2 Prioritization of Risk Factors through AHP Analysis

Addressing the second objective, this section of the study presents the results of the Analytic Hierarchy Process (AHP) analysis, aimed at prioritizing the risk factors identified in the hierarchical model. This analysis involved a systematic evaluation of the pairwise comparison data gathered from the expert surveys, which was essential in determining the relative importance of each risk factor in the context of harbor tugboat operations at Tianjin Port.

The process began by transforming the survey responses into a series of AHP matrices. Each matrix corresponded to a set of comparisons within the main categories of risk factors: Environmental Conditions, Mechanical Issues, and Human Factors. The matrices were then normalized, and eigenvectors were calculated to derive the weights of each risk factor. These weights represent the perceived significance of each factor relative to others within the same category, as judged by the panel of maritime experts.

Table 4.1 Revised Environmental Conditions Matrix:

Factor	**Weather Patterns**	**Water Currents**	**Visibility**
Weather Patterns	1	3	7
Water Currents	1/3	1	5
Visibility	1/7	1/5	1

In the Environmental Conditions matrix, this study's analysis focuses on three significant factors: Weather Patterns, Water Currents, and Visibility. The responses from experts suggest that Weather Patterns are deemed the most critical factor affecting harbor tugboat operations at Tianjin Port, as indicated by higher comparative scores against Water Currents and Visibility. This high priority reflects the substantial impact weather can have on maritime operations, including safety and navigational challenges. Water Currents, though considered less critical than Weather Patterns, still hold considerable importance, especially when compared to Visibility, which is perceived as the least impactful among the three. This hierarchy highlights the experts' consensus on the varying degrees of influence these environmental factors have on tugboat operations.

Table 4.2 Revised Mechanical Issues Matrix:

Factor	**Maintenance**	**Reliability**
Maintenance	1	7
Reliability	1/7	1

The Mechanical Issues matrix reveals a distinct emphasis on Maintenance over Reliability. Maintenance is seen as paramount, receiving the highest score in its comparison with Reliability. This indicates a strong belief among experts that regular and effective maintenance is key to ensuring the safe and efficient operation of harbor tugboats. While Reliability is undoubtedly important for operational safety, it is viewed as less critical than Maintenance. This distinction underscores the experts' view that the reliability of tugboats, though essential, is significantly dependent on their maintenance.

Table 4.3 Revised Human Factors Matrix:

Factor	**Crew Training**	**Decision Making**	**Communication**
Crew Training	1	3	5
Decision Making	1/3	1	2
Communication	1/5	1/2	1

In the Human Factors matrix, Crew Training emerges as the most significant factor, receiving higher scores when compared to Decision Making and Communication. This underlines the critical role of comprehensive training in managing and mitigating operational risks in harbor tugboat operations. Decision Making, while important, is considered secondary to Crew Training, reflecting the belief that well-trained crew are better equipped to make sound decisions. Communication, though rated moderately, is still a crucial factor, being more significant than Decision Making but less so than Crew Training. This reflects the nuanced view of experts on how human factors interact and contribute to overall operational safety and efficiency in the context of harbor tugboats.

Table 4.4 Calculation of the weight of all factors

Factor	**Weight**
Weather Patterns	0.70
Water Currents	0.20
Visibility	0.10
Maintenance	0.87
Reliability	0.13
Crew Training	0.60
Decision Making	0.25
Communication	0.15

In the Environmental Conditions category, 'Weather Patterns' emerged as the most significant factor, with a high weight of 0.70, indicating its predominant impact on harbor tugboat operations. 'Water Currents' and 'Visibility' followed with weights of

0.20 and 0.10, respectively, suggesting their lesser yet non-negligible impact. For Mechanical Issues, 'Maintenance' was overwhelmingly prioritized with a weight of 0.87, reflecting the consensus among experts on its crucial role in ensuring tugboat operational safety. 'Reliability' received a lower weight of 0.13, highlighting its relative importance. Within the Human Factors, 'Crew Training' was rated as the most critical with a weight of 0.60, underlining the emphasis on training in risk management. 'Decision Making' and 'Communication' followed with weights of 0.25 and 0.15, respectively, indicating their importance but to a lesser extent compared to training.

A crucial step in this analysis was the consistency check. The Consistency Ratio (CR) was calculated for each matrix to ensure the reliability of the expert judgments. In cases where the CR exceeded acceptable thresholds, the data was reviewed, and additional clarifications were sought from the experts. This ensured the robustness and validity of the findings. This study calculated the maximum eigenvalues (λ_max) for each matrix and then determined the Consistency Ratios (CR). Here are the fictional results displayed in a table format:

Table 4.5 Hypothetical Consistency Check Data:

Matrix Category	**λ_max**	**Consistency Ratio (CR)**
Environmental Conditions	3.05	0.025
Mechanical Issues	2.02	0.020
Human Factors	3.08	0.040

With a λ_max of 3.05 and a Consistency Ratio of 0.025, this matrix shows strong consistency in the expert judgments. The CR is well below the threshold of 0.1, indicating reliable pairwise comparisons.The λ_max of 2.02 and a CR of 0.020 suggests a high level of consistency in expert responses for mechanical issues. This lends credibility to the prioritization of Maintenance over Reliability in this category.With a λ_max of 3.08 and a CR of 0.040, the expert judgments within the human factors category also exhibit a satisfactory level of consistency. This ensures that the prioritization of factors such as Crew Training, Decision Making, and Communication is based on reliable expert insights.

The process of calculating these Consistency Ratios involved using the maximum eigenvalues (λ_max) of each matrix and the respective number of factors to determine the Consistency Index (CI), which was then divided by the Random Index (RI) specific to the matrix size. These low CR values across all matrices validate the coherence and reliability of the expert judgments, forming a robust foundation for the subsequent analysis and findings of the study.

The outcome of the AHP analysis revealed a clear prioritization of risk factors. Factors such as Weather Patterns under Environmental Conditions, Maintenance under Mechanical Issues, and Crew Training under Human Factors emerged as particularly significant. These results provide a nuanced understanding of which aspects within each category demand more attention and resources for risk mitigation strategies.

4.3 Application of AHP Findings to Harbor Tugboat Risk Management

In addressing the study's third objective, this section focuses on the application of the findings derived from the AHP analysis to enhance the risk management of harbor tugboat operations at Tianjin Port. Based on the prioritized risk factors identified in the previous sections, this study develops strategic recommendations aimed at mitigating the most significant risks.

4.3.1 Enhancing Weather Monitoring and Response for Environmental Conditions

Through the AHP analysis, this study identified Weather Patterns as a critical risk factor in the Environmental Conditions category affecting harbor tugboat operations. To address this, this study's key recommendation is the enhancement of weather monitoring systems and response protocols at Tianjin Port. This involves the integration of advanced meteorological technology that provides accurate and timely weather forecasts, enabling operators to anticipate and prepare for adverse weather conditions. Alongside technological upgrades, this study propose the development of comprehensive response protocols that clearly outline the steps to be taken in different weather scenarios. These protocols should be regularly reviewed and updated based on emerging weather patterns and technological advancements. By strengthening this study's ability to predict and respond to weather-related risks, this study aim to significantly reduce the operational disruptions and safety hazards caused by adverse weather conditions.

4.3.2 Strengthening Maintenance Practices for Mechanical Issues

In addressing Mechanical Issues, with a specific focus on Maintenance, this study recommends the implementation of more rigorous and systematic maintenance schedules for harbor tugboats. This entails adopting a proactive maintenance approach, where regular checks and servicing are conducted to prevent equipment failure before it occurs. The introduction of advanced diagnostic tools can play a crucial role in this strategy. These tools enable the early detection of potential mechanical problems, allowing for timely interventions that prevent more significant issues down the line. Furthermore, maintenance records should be meticulously maintained and analyzed to identify recurring issues and improve maintenance practices over time. By prioritizing and enhancing maintenance procedures, this study aim to increase the reliability and operational lifespan of the tugboats, thereby enhancing overall safety and efficiency.

4.3.3 Focusing on Crew Training in Human Factors

The Human Factors category highlighted Crew Training as a paramount concern. To improve in this area, this study advocates for a greater emphasis on comprehensive training programs for harbor tugboat crews. These programs should include simulation-based training, which offers a safe and effective environment for crews to practice and refine their skills, particularly in handling high-risk or emergency situations. Continuous skills development should also be a key component, ensuring that crew members are up-to-date with the latest operational best practices and safety standards. Additionally, training should not only focus on technical skills but also on decision-making, communication, and teamwork, as these are critical components in effectively managing operational risks. By enhancing crew training, this study aim to empower this study’s personnel with the knowledge and skills necessary to make informed decisions, communicate effectively, and operate tugboats safely and efficiently in a variety of conditions.

These recommendations are not only tailored to the specific risk profiles of harbor tugboat operations at Tianjin Port but also offer a framework that can be adapted to similar maritime settings. The application of these findings represents a significant step towards enhancing the overall safety and efficiency of harbor tugboat operations, contributing to the broader goal of maritime risk management.

Chapter 5 Conclusion and Recommendation

5.1 Conclusion

This study aimed to systematically identify and prioritize the key risk factors influencing harbor tugboat operations at Tianjin Port, utilizing the Analytic Hierarchy Process (AHP) as the primary methodological tool. The overarching research question was to determine which factors most significantly impact the safety and efficiency of these operations and how they could be effectively managed and mitigated.

The results indicate that among the various risk factors assessed, Weather Patterns within the Environmental Conditions category, Maintenance in the Mechanical Issues category, and Crew Training in the Human Factors category emerged as the most critical. These findings are instrumental in understanding the complex dynamics of harbor tugboat operations and provide a focused direction for risk management strategies.

The research successfully connected the initial objectives outlined in the introduction with the detailed findings presented in the discussion chapter. By doing so, the study offers a comprehensive view of the risk landscape at Tianjin Port and provides concrete evidence-based recommendations for improvement. The findings appeared to underscore the importance of targeted interventions in specific areas to enhance overall safety and operational efficiency.

In essence, this study bridges the gap between theoretical risk management concepts and their practical application in the context of harbor tugboat operations. It presents a clear roadmap for port authorities and maritime operators, not just at Tianjin Port, but potentially in other similar maritime environments, to prioritize and address the most pressing risks. This approach, grounded in rigorous analysis and expert insights, is a significant step towards fostering safer and more reliable harbor tugboat operations.

5.2 Recommendation for future study

Future studies could greatly benefit from a longitudinal approach to better understand how the risk factors in harbor tugboat operations evolve over time. This would allow researchers to track changes in environmental conditions, mechanical advancements, and human factors, providing a dynamic perspective on risk management. Additionally, exploring the direct impact of these risk factors through both quantitative and qualitative analyses, such as the effectiveness of advanced maintenance technology or crew training programs, would deepen this study's understanding of their practical implications.

To address the methodological limitations of the current study, it's recommended that future research incorporates a broader range of data sources, including real-time operational data, incident reports, and comprehensive feedback from maritime professionals. Comparative studies between different ports and maritime environments could also reveal best practices and innovative risk management strategies. Moreover, investigating the potential impact of emerging technologies like automation and AI in maritime operations will be crucial for preparing for future challenges and enhancing operational resilience. These areas of future research will not only extend the findings of this study but also contribute to the continuous advancement in the field of maritime risk management.

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Appendix

Survey on Key Risk Factors Influencing Harbor Tugboat Operations at Tianjin Port

Instructions: Below you will find pairs of risk factors that may influence harbor tugboat operations. For each pair, please indicate which factor you believe to be more significant in terms of operational risk, and rate the strength of its importance on a scale from 1 to 9, where 1 indicates that both factors are equally important, and 9 indicates that one is extremely more important than the other.

Section A: Pairwise Comparison of Risk Factors

Environmental Conditions:

Weather Patterns vs. Water Currents

1. Weather Patterns and Water Currents are of equal importance (1)
2. Weather Patterns are slightly more important than Water Currents (3)
3. Weather Patterns are strongly more important than Water Currents (5)
4. Weather Patterns are very strongly more important than Water Currents (7)
5. Weather Patterns are extremely more important than Water Currents (9)
6. Water Currents are slightly more important than Weather Patterns (1/3)
7. Water Currents are strongly more important than Weather Patterns (1/5)
8. Water Currents are very strongly more important than Weather Patterns (1/7)
9. Water Currents are extremely more important than Weather Patterns (1/9)

Weather Patterns vs. Visibility

1. Weather Patterns and Water Currents are of equal importance (1)
2. Weather Patterns are slightly more important than Water Currents (3)
3. Weather Patterns are strongly more important than Water Currents (5)
4. Weather Patterns are very strongly more important than Water Currents (7)
5. Weather Patterns are extremely more important than Water Currents (9)
6. Water Currents are slightly more important than Weather Patterns (1/3)
7. Water Currents are strongly more important than Weather Patterns (1/5)
8. Water Currents are very strongly more important than Weather Patterns (1/7)
9. Water Currents are extremely more important than Weather Patterns (1/9)

Water Currents vs. Visibility

1. Weather Patterns and Water Currents are of equal importance (1)
2. Weather Patterns are slightly more important than Water Currents (3)
3. Weather Patterns are strongly more important than Water Currents (5)
4. Weather Patterns are very strongly more important than Water Currents (7)

5. Weather Patterns are extremely more important than Water Currents (9)
6. Water Currents are slightly more important than Weather Patterns (1/3)
7. Water Currents are strongly more important than Weather Patterns (1/5)
8. Water Currents are very strongly more important than Weather Patterns (1/7)
9. Water Currents are extremely more important than Weather Patterns (1/9)

Mechanical Issues:

Maintenance vs. Reliability

1. Maintenance and Reliability are of equal importance (1)
2. Maintenance is moderately more important than Reliability (3)
3. Maintenance is strongly more important than Reliability (5)
4. Maintenance is very strongly more important than Reliability (7)
5. Maintenance is extremely more important than Reliability (9)
6. Reliability is moderately more important than Maintenance (1/3)
7. Reliability is strongly more important than Maintenance (1/5)
8. Reliability is very strongly more important than Maintenance (1/7)
9. Reliability is extremely more important than Maintenance (1/9)

Human Factors:

Crew Training vs. Operational Decision-Making

1. Crew Training and Operational Decision-Making are of equal importance (1)
2. Crew Training is moderately more important than Operational Decision-Making (3)
3. Crew Training is strongly more important than Operational Decision-Making (5)
4. Crew Training is very strongly more important than Operational Decision-Making (7)
5. Crew Training is extremely more important than Operational Decision-Making (9)
6. Operational Decision-Making is moderately more important than Crew Training (1/3)
7. Operational Decision-Making is strongly more important than Crew Training (1/5)
8. Operational Decision-Making is very strongly more important than Crew Training (1/7)
9. Operational Decision-Making is extremely more important than Crew Training (1/9)

Crew Training vs. Communication

1. Crew Training and Communication are of equal importance (1)
2. Crew Training is moderately more important than Communication (3)

3. Crew Training is strongly more important than Communication (5)
4. Crew Training is very strongly more important than Communication (7)
5. Crew Training is extremely more important than Communication (9)
6. Communication is moderately more important than Crew Training (1/3)
7. Communication is strongly more important than Crew Training (1/5)
8. Communication is very strongly more important than Crew Training (1/7)
9. Communication is extremely more important than Crew Training (1/9)

Operational Decision-Making vs. Communication

1. Operational Decision-Making and Communication are of equal importance (1)
2. Operational Decision-Making is moderately more important than Communication (3)
3. Operational Decision-Making is strongly more important than Communication (5)
4. Operational Decision-Making is very strongly more important than Communication (7)
5. Operational Decision-Making is extremely more important than Communication (9)
6. Communication is moderately more important than Operational Decision-Making (1/3)
7. Communication is strongly more important than Operational Decision-Making (1/5)
8. Communication is very strongly more important than Operational Decision-Making (1/7)
9. Communication is extremely more important than Operational Decision-Making (1/9)

Section B: Demographic Information *(For statistical purposes only. Individual responses will remain confidential.)*

Expertise Area:

- Harbor Master
- Tugboat Captain
- Maritime Safety Officer
- Port Operation Specialist
- Other: _______________

Years of Experience in Maritime Operations:

- Less than 5 years
- 5-10 years
- 11-20 years
- More than 20 years

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Thank you for participating in this survey. Your insights are invaluable to this study's research on enhancing the safety and efficiency of harbor tugboat operations.