

Identifying critical risk factors and responses of river dredging projects for knowledge management within organisation

Jui-Sheng Chou  | Ying-Chen Chiu

Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan

Correspondence

Jui-Sheng Chou, Department of Civil and Construction Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan.
Email: jschou@mail.ntust.edu.tw

Funding information

Ministry of Science and Technology, Taiwan, Grant/Award Number: 108-2221-E-011-003-MY3

Abstract

A river exhibits strong upstream erosion and rapid downstream accumulation. Dredging is one of the methods that is most commonly adopted by the Taiwan Water Resources Agency (WRA) to ensure the smooth flow of rivers and their ability to discharge water, protecting lives and property from flood disasters. However, dredging projects are large, involving very many stakeholders, leading to high uncertainty in the implementation of the project. The WRA also lacks relevant risk management methods and countermeasures owing to the periodical brain drain and retirement within the organisation. In order to enhance risk management for dredging engineers, river management offices across the country were visited, and knowledge and experience of dredging engineering were obtained using expert meetings and scientific methods. Work was carried out with the WRA to identify six major risk categories for dredging projects, covering 30 risks. An Analytic Hierarchy Process (AHP) questionnaire was developed using the Risk Breakdown Structure (RBS), and a Risk Impact/Frequency Analysis (RIFA) questionnaire was developed using the Important/Performance Analysis (IPA) method; these were answered by 69 engineers with experience in river dredging. Finally, critical risk factors are identified and ranked by combining the responses to the questionnaires and in the interviews, helping engineers with risk management in the future. Research results demonstrate that most of the engineering management experience in practice is communicated by word of mouth, with no effective and systematic method of knowledge management. Therefore, a knowledge-based system is created, covering 170 risk events and solutions for various dredging projects, and a graphical user information system is built in a programming language, to enable the WRA to save engineering experience systematically for future exploitation.

KEYWORDS

critical risk factors, dredging engineering project, flood management, knowledge management, risk identification and flood mitigation, risk response, river restoration

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.

© 2021 The Authors. *Journal of Flood Risk Management* published by Chartered Institution of Water and Environmental Management and John Wiley & Sons Ltd.

1 | INTRODUCTION

Risk is an event about uncertain future, which is the possibility or chance of loss, danger or injury. The risk may bring loss to stakeholders. Uncertainty is the core of risk. All kinds of risks are hidden in any project. Understandably, actively avoiding and dissolving the project risks is critical to the efficient operations of engineering execution (Zhu, Pan, Miao, & He, 2017). River dredging is a type of water conservancy projects, which is a combination of investment and construction activities subjected to various risks to be managed, such as social and political risk, natural disaster risk, financial risk, technical risk, construction contract legal risk, operational risk and environmental risk.

Taiwan is an island country that is narrow east-to-west and has a central mountain range that runs from north to south. Its rivers mostly flow to the east and west of the main watersheds from the Central Mountain Range into the sea and are characterised by short flow paths, narrow watersheds, large slopes, and high flow velocities. Moreover, because of frequent earthquakes and typhoons in Taiwan as well as other climatic, geological, and topographical conditions, most of the rivers

exhibit strong upstream erosion and rapid accumulation downstream, which affect their smooth flow.

Since Taiwan is densely populated, river dredging has become one of the methods that is often adopted by the Water Resources Agency (WRA) to protect the lives and properties of coastal residents and to prevent the reduction of flood discharge capacity by soil and sand siltation. The WRA is a central government agency that manages major rivers in Taiwan. It gathers historical data on various dredging projects, provides past experience in risk management, and employs hundreds of engineers with an abundance of experience in dredging.

According to Taiwan's regulations concerning river management, rivers under the jurisdiction of the central government are managed by 10 River Management Offices that are affiliated with the WRA. River areas under the management of the central government include 25 central river water systems (including Tamsui river, Lanyang river, and Heping river) and two interprovincial water systems (the Tamsui river system and the Sulfur Creek river system), as presented in Figure 1. Rivers under the jurisdiction of the central government are the key targets of annual plans for river management. Dredging projects can ensure the stability

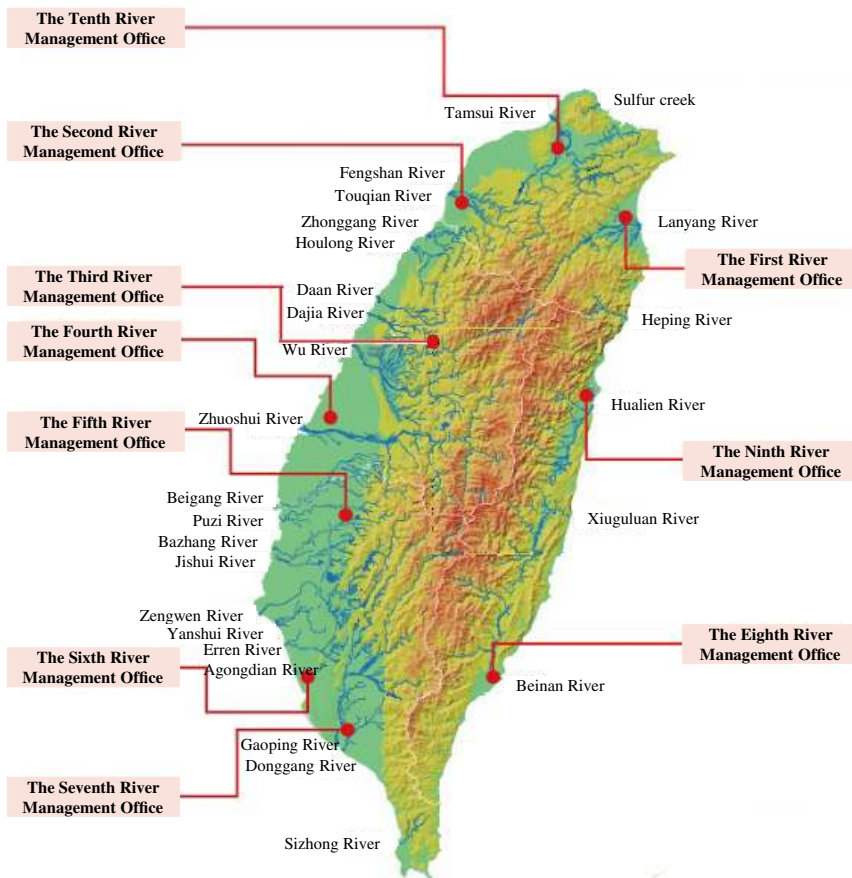


FIGURE 1 Rivers administered by the central government

of flow paths, and the sand and gravel that is mined in the dredging process can be put to various purposes, such as when used as construction materials.

River dredging projects were used to be handled in accordance with the Procurement Act, which required that the mining and sale of sand and gravel are conducted together, resulting in a single winning bidder. Sources of sand and gravel may be dispersed so complete control of the quantity of transported sand and gravel was unfeasible on site. This conventional tendering strategy therefore presents an extremely high risk of illegal mining in unlicensed areas and over excavation, and supports the easy manipulation of the prices of sand and gravel.

In 2006, to control the amount of sand and gravel mined, exported, and sold, the WRA settled on a new policy to promote the separation of mining and sales, increasing the supervision of workforce and regulatory facilities (including control stations, weighbridges, and monitoring systems). In the case of acceptance of a dredging project, the cross section is examined, and the sand and gravel to be sold are monitored using a weight control method. The implementation of this policy has been proved to be effective in preventing illegal mining, and has become the main method for handling domestic dredging projects.

However, like the worldwide phenomenon (Willumsen, Oehmen, Stingl, & Geraldi, 2019) the agency lacks systematic management methods to preserve and analyse past information, which could be used to improve risk-informed decision in project management. This investigation identifies relevant risk factors through interviews with River Management Officers across the country about their experiences to create a risk breakdown structure (RBS). Risk management methods were then adopted to analyse the risk factor priorities for immediate control and response by management units. Finally, on the basis of the responses in interviews, a dredging project risk knowledge base was developed to retain systematically information about past risk events and methods of disposal, according to the life cycle of dredging projects. Decision-makers are thus provided with immediate and correct methods for risk management, favouring risk avoidance and prevention.

The rest of this paper is organised as follows. Section 2 reviews pertinent literature related to risk management in public works, decision-making methods and processes for engineering projects, and advantages of knowledge-based systems for risk response. Section 3 then describes the research methods. Section 4 discusses the on-site interviews and RBS formulation. Section 5 presents the analyses of questionnaires and risk factors. Section 6 demonstrates the design and implementation of

knowledge-based system for risk control and response. Finally, Section 7 concludes with remarks and recommendations.

2 | LITERATURE REVIEW

2.1 | Risk management used in public works

Risk management has been widely used globally in large-scale public works, such as the construction of roads, tunnels, railways and international hub airports (Chen, Li, Ren, Xu, & Hong, 2011), and the generation of hydroelectric, thermal, and nuclear power (Miller & Lessard, 2001). Hallowell, Esmaeili, and Chinowsky (2011) conducted a quantitative analysis of 25 risks by using the Delphi method to evaluate the risks to safety associated with highway construction in the United States (Hallowell et al., 2011). El-Sayegh and Mansour (2015) established an RBS for road construction in the United Arab Emirates and calculated the probabilities, effects, and priorities of risks using a relative importance index (El-Sayegh & Mansour, 2015). Perera, Rameezdeen, Chileshe, and Hosseini (2014) identified the most critical risk factor in the life-cycle of a highway construction project in Sri Lanka using the Delphi method; they used the concept of knowledge management to improve project risk management (Perera et al., 2014).

Various Asian countries with a geographical location and customs and traditions similar to those of Taiwan have been successful in applying risk management for public works. Yanagisawa et al. (2007) simulated changes in seawater levels that are caused by tsunamis in the coastal areas of Japan to evaluate the risk factors of the operation and management of coastal nuclear power facilities (Yanagisawa et al., 2007). Seo and Choi (2008) listed the risks of a Korean subway construction project and conducted an impact assessment and case analysis to generate a safe construction plan at the design stage (Seo & Choi, 2008). Ghosh and Jintanapakanont (2004) assessed the key risk factors in the construction of a Thai underground mass rapid transit system (the Chaloe M Ratchamongkhon line) and arranged them in priority order (Ghosh & Jintanapakanont, 2004). Hosny, Ibrahim, and Fraig (2018) noted that risk management implementation in a project can greatly increase its likelihood of success (Hosny et al., 2018). Risk control can be optimised by identifying the risk factors in a project, arranging them in priority order, and controlling those higher up on the list (Muriana & Vizzini, 2017).

In summary, risk management is widely used in large-scale public works around the world, reflecting its

importance to such projects. Therefore, in this investigation, a systematic risk management technique is developed to help the WRA construct strategic plan in risk mitigation and response.

2.2 | Arranging factors in priority order using an analytic hierarchy process

For the purpose of prioritising risk factors on the basis of the knowledge and experience of professionals, the analytic hierarchy process (AHP) is one of the most effective methods for evaluating multi-criteria decision-making and subjective judgement (Huang, Chu, & Chiang, 2008). Lee and Lee (2015) used the AHP to arrange Korean tourism industry policies in order of priority for the development of a tourism promotion strategy (Lee & Lee, 2015). Ghimire and Kim (2018) used the AHP to rank barriers to the development of renewable energy in Nepal (Ghimire & Kim, 2018). Anjasmoro, Suharyanto, and Sangkawati (2017) asserted that eight areas suffered from severe water shortages after years of feasibility studies in the Semarang region in Indonesia, and a small emergency dam had to be built within a limited time and with restricted funds. In this case, the AHP was used to analyse the priorities in the construction of a dam (Anjasmoro et al., 2017). Unutmaz Durmuşoğlu (2018) used the AHP to evaluate key successful projects of Turkish technological entrepreneurs (Unutmaz Durmuşoğlu, 2018). Liberatore (1987) explored the usefulness of the AHP in prioritising projects and allocating resources for industrial research and development (Liberatore, 1987). Therefore, the AHP has been proven to be an effective priority ranking method, and its factor prioritisation function is well-recognised in the engineering field.

2.3 | Using importance–performance analysis to assess the feasibility of risk management

Various risk studies have identified that the frequency and impact of risks are crucial elements in risk management (Duddu, Kukkapalli, & Pulugurtha, 2019; Karasan, Ilbahar, Cebi, & Kahraman, 2018; Khaloie, Abdollahi, Rashidinejad, & Siano, 2019), which cannot be evaluated through the AHP. Thus, one method, namely importance–performance analysis (IPA) can be carried out to consider the frequency and impact of risks on the target. As an intuitive and easy-to-understand analytical method, IPA presents results in quadrant graphs, and is therefore used in the field of business management in support of marketing decisions (Karthiyayini, Rajendran, & Kumaravel, 2018). IPA is also

used in public transportation (Rodriguez-Valencia, Rosas-Satizabal, & Paris, 2019), the improvement of higher education (Palmer & O'Neill, 2004), and public management decision-making (Lai & To, 2010), so it has a wide range of applications.

Numerous studies have extended and improved the assessment items in IPA according to the characteristics of the research objectives. To compensate for the shortcomings of IPA in analysing competitive relationships, Dolinsky (1991) changed the assessment items for a national sample of Health Maintenance Organization (HMO) members to level of importance, performance on our side, and performance on the competitor(s) (Dolinsky, 1991). The study indicated that improper strategies may result if a competition dimension is not involved in the analysis. Medina-Muñoz and Medina-Muñoz (2014) added satisfaction as an assessment item to evaluate the experiences of visitors to Gran Canaria, Spain (Medina-Muñoz & Medina-Muñoz, 2014).

In sum, the aim of this work is to replace IPA factors with risk frequency and impact, to interview experienced engineers, and to adopt AHP rankings to prioritise risk factors in a comprehensive and easily understandable analytical approach.

2.4 | Knowledge-based management for risk response

Risk management practices rely on not only the prioritising of risk factors but also the use of experience and knowledge in decision-making (Ding, Zhong, Wu, & Luo, 2016; Han, Kim, Kim, & Jang, 2008; Karasan et al., 2018; Tserng et al., 2009). Serpella, Ferrada, Howard, and Rubio (2014) claimed that the most effective risk management method requires knowledge and experience in addition to effective disposal of risk during construction project execution (Serpella et al., 2014). Liebowitz (1999) argued that a knowledge base is the core of an organisation's computer and online storage of relevant knowledge, documents, and professional skills in a certain field, and that the content in a knowledge base should be integrated, filtered, indexed, and classified, as one of the core tools in organisational knowledge management (Liebowitz, 1999).

3 | RESEARCH METHODS

To establish a knowledge base, an organisation must first collect and organise original data, classify and save them using information technology (IT) methods, and provide a corresponding search tool to systemize said information, experience, and knowledge. This study interviewed

the dredging personnel of the River Management Offices to extract their experience and knowledge of risk events and elicit practical solutions. The Knowledge Base is divided into six major categories, namely technology, nature, economics and society, laws and contracts, organisation, and management capability, corresponding to a total of 30 risk factors for future reference by dredging engineers at the River Management Offices. The research flow chart for this study is shown in Figure 2 and described in the following subsections.

3.1 | In-depth and focus group interviews

The function of in-depth interviews is to obtain a deep and solid understanding of the interviewees. Therefore, depth is a more important criterion than breadth (Rubin & Rubin, 2005). According to Wiess (1994), the observations of some interviewees who profoundly understand the considered phenomena could provide more information than the observations of hundreds of others (Wiess, 1994). After reviewing the basic literature and performing a preliminary analysis, the researchers

performed in-depth interviews of competent authorities in agencies responsible for executing, reviewing or consulting dredging engineering projects.

The objective of these interviews was to identify the obstacles that these agencies encounter when promoting hydraulic engineering and flood control projects, the challenges presented by the systems, and the methods used to resolve the problems. During the interview process, the competent authorities and review agency officials for the case projects offered their personal experiences in addressing these issues and their personal perspectives, which were used for reference in further case analysis and system designs.

A focus group interview is a carefully planned series of discussions with a selected group under specified conditions. The goal of the interviews is understanding the feelings and opinions of professionals regarding certain topics, products, or services (Krueger & Casey, 2000). After the literature review, this study performed in-depth interviews and a case analysis before drafting the RBS and questionnaires for project initiation and execution as well as relevant supporting methods for developing feasible operating procedures, provisions, and relevant measures. Scholars and experts were then invited to host seminars to study, discuss, and review the formulated standards and procedures. The objective was to apply the ideas and suggestions resulting from the study to ensure that their implementation was practical and feasible.

3.2 | Case analysis

A case analysis, or case study, is a research design for analysing the specific and complete morphology of events within a limited time. In addition to providing definite evidence to support abstract theories, this design provides insight into specific units as the basis for cross-level inferences (Gerring, 2007; Niehaves, Plattfaut, & Becker, 2013). Therefore, based on the foundation established by the literature review and in-depth interviews with competent authorities and review agency officials, this study analysed the background, planning, review processes, current implementation status, implementation difficulties, project objectives, and realised benefits of dredging projects to identify causes of project failure regarding unsuccessful initiation prevention, budget overrun, and overdue schedules. The management methods and strategies adopted by the agencies-in-charge, competent authorities, and review agencies were obtained concurrently to provide references for constructing strategies of risk identification, mitigation, and response.

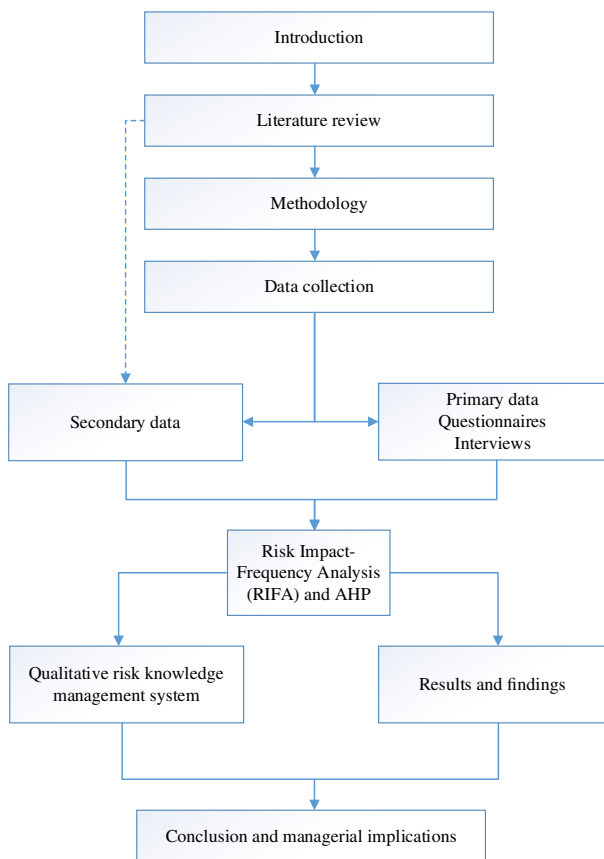


FIGURE 2 Research flowchart

3.3 | Basic assumptions and implementation steps of the AHP

Most risk management frameworks were elicited by brainstorming with experts, who were drawing on their experience, during which the sources and impact of risk were discussed. Different discussion teams may produce distinctively different results. To enable future dredging units to have a consistent common language when discussing matters that relate to risk management for dredging projects, an AHP was used herein to conduct a quantitative analysis of risks, comprehensively considering all risk sources and factors, integrating the professional experience of dredging personnel from each unit, and determining the priorities of the risk factors.

The AHP can filter questionnaires with high credibility through a consistency test, which is more logical than conventional approaches, such as panel discussion, and considers multiple decision criteria. Therefore, it can provide decision-makers with more effective information. The use of the AHP to solve actual problems involves five steps, which are establishment of the problem and confirmation of goals, establishment of the hierarchical structure for evaluation criteria and alternatives, questionnaire design and survey, checking of consistency, and priority rank determination (Saaty, 1994).

3.4 | Implementation of IPA and situations in which it is applied

IPA is a commercial analysis method that was developed by Martilla and James (1977) to identify underperforming products and services (Martilla & James, 1977). Because of its simple and easy-to-understand characteristics, IPA is used in various fields. IPA usually involves the evaluation of customers' emphases on, and perceptions of, particular aspects of products and services to enable improvement measures to be adopted based on degree of importance and performance. The IPA can be used to draw an analysis map in the form of a two-dimensional matrix. The performance of any item can be described by its relative position on the four quadrants, which provides a basis for researchers to adjust the priorities of products and services to be improved.

3.5 | Rationale and tools for constructing knowledge base

Knowledge base refers to relevant knowledge, experience, documents, and professional skills in a domain that are stored in a computer and online (Liebowitz, 1999;

Mockler & Dologite, 1988). In particular, up-to-date and implicit engineering experience can be integrated, filtered, indexed, classified, and processed, and represents the central tool in an organisation's knowledge management. Since a knowledge base is a collection of pieces of specialised information or expert knowledge of any type, it can support the inference of the characteristics of all knowledge in any field as a basis for completing complex tasks.

To establish a knowledge base, a large-scale collection and summarization of original data must be performed. The knowledge should be classified and saved according to IT methods, and a corresponding search system should be provided to access the knowledge. In this study, a Dredging Engineering Knowledge Base was established using programming languages (i.e., MySQL and Python) to create a risk management information system for use by engineers or project managers to retrieve relevant knowledge and solutions when they encounter risks in any phase of a project life cycle.

4 | ON-SITE INTERVIEWS AND RBS FORMULATION

4.1 | On-site interview responses and information collection

The researchers visited 10 River Management Offices and central authorities in the country and interviewed their staff to understand the risk-related issues and events that the River Management Offices often encounter. The preliminary results revealed that the River Management Offices faced different issues, and that risk events were closely related to the planned dredging project content, natural environment, market, stakeholders and political factors, which are generally consistent with the literature (Xia, Zou, Griffin, Wang, & Zhong, 2018). Although each River Management Office encountered different risk events and risk factors, an inductive analysis of subcategory and structure could still be performed to determine the sources and causes of the risk events.

After numerous discussions with the engineering personnel of the WRA, the life cycle of a dredging project that was implemented in a manner consistent with the principle of separated mining and sales practices was formulated (Table 1). Thus, the life cycle of such projects is divided into nine stages, and the tasks to be completed in each stage are sequenced as a sub process of the life cycle. By doing so, not only was the time of a possible risk event determined; the WRA was enabled herein to retain all relevant processes of dredging project. In this investigation, the

TABLE 1 Life cycle of dredging project

Stage	Description
Initial stage	The owner develops project documentation and administrative procedure.
Planning stage	All possible options have been measured, and a single project has been recognised with cost-effective and economic requirement.
Design stage	The initial strategy is then developed into a complete engineering design package.
Bidding stage	The total packet of tender booklets will be collected including all tendering criteria. Then, contractors are requested to submit their proposals.
Preparation stage	All project workers have to contribute their knowledge and skill to the preparation of the employed method and planning of the process.
Construction stage of the peripheral facilities	This stage is to produce full provisions for the agreement documents and establish management structure and review system.
Discharge construction and monitoring stage	The project contractors implement the dredging work and construction monitoring.
Completion and acceptance stage	Upon the achievement of the construction phase a design should be in place to make sure that the operation and maintenance of the dredging project continues in a way to ensure the project purposes correctly.
Final stage	Provisions should be made from the start and included in the overall design and planning upon final acceptance of the dredging project.

respondents were asked to assess risks for construction stage in the life cycle of a dredging project.

4.2 | Framework of RBS

To manage and identify possible risk factors, an RBS was jointly established with the WRA after repeated discussions with its representatives. The main objective in establishing an RBS is to classify systematically and effectively all possible risk factors for dredging projects,

which can help dredging personnel to identify risks before they conduct a dredging project and to plan relevant countermeasures as early as possible. An RBS also favours risk prevention, improving project execution.

To validate contents of the RBS, the researchers invited dredging engineering experts from the WRA and relevant scholars to participate in an expert (focus group) meeting. The primary objective was to determine the primary RBS of dredging projects through brainstorming, particularly by referencing relevant theories as well as experiences and insights that have been accumulated through the past dredging projects. After numerous discussions, the risks of dredging projects were divided into six major categories, namely technology, nature, economics and society, laws and contracts, organisation, and management capability. Figure 3 displays a total of 30 detailed risk factors in the characteristics of these major risk categories.

5 | DESIGN AND ANALYSIS OF QUESTIONNAIRE

5.1 | Logic of design of questionnaire structure

According to the aforementioned RBS, a questionnaire was designed to quantify the impact, frequency, and weight of each risk factor. It was completed by experienced dredging personnel of the River Management Offices. The questionnaire was divided into three parts, which covered each participant's background, risk impact–frequency analysis (RIFA), and AHP.

The first part was a background check of the participants to understand their working units and titles. In the second part, RIFA was carried out to understand the impact and frequency of various risk factors based on the experience of the participants. The third part was an AHP questionnaire with a bottom-up design, which differed from conventional hierarchical analysis methods. A pairwise comparison of third-level risk-factors (Figure 3) was carried out at first to increase participants' understanding of the listed factors in RBS. This part of the questionnaire included bottom-level risk factors, middle-level risk sources, and top-level objective.

In addition to providing a risk factor table to explain the risk factors that affected the comprehensive benefits of the dredging project, the questionnaire contained long keyword descriptions to help participants recall the problems and risks that they encountered when undertaking past dredging projects, which enabled them to compare and answer accurately. Only after the respondents understood in detail the definitions of six major risk sources and risk factors were they asked to complete the

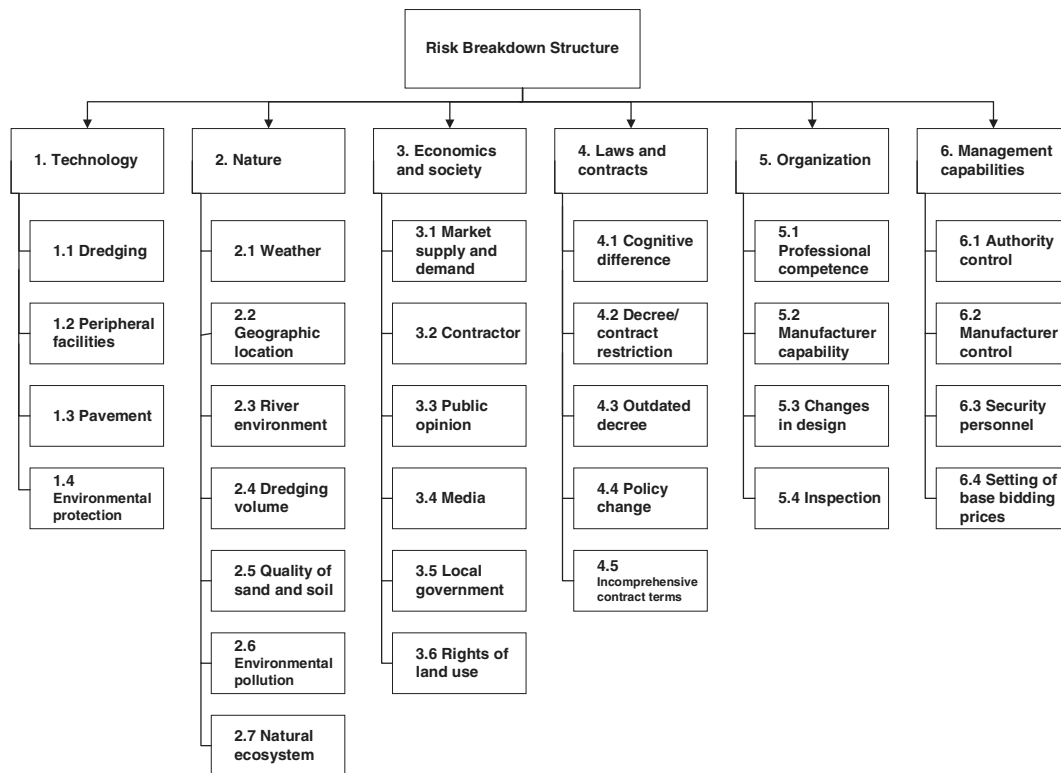


FIGURE 3 Risk breakdown structure

questionnaire on the pairwise comparison of six middle-level risk sources. Therefore, the validity of the questionnaire was increased and the experience of the participants was appropriately captured by it.

5.2 | Questionnaire analysis and ranking of risk factors

5.2.1 | Background of participants

The respondents to the questionnaire were experienced engineering personnel who had handled dredging projects in Taiwan (Table 2). A total of 69 completed questionnaires were collected from 10 River Management Offices and their central authority, which is the WRA. The questionnaire elicited responses from personnel in River Management Offices across the country. The results were reliable because the questionnaire collected comprehensive opinions from professionals at all levels.

5.2.2 | Risk impact-frequency analysis

Questionnaire responses concerning impact and frequency

The questionnaire targeted the impact and frequency of 30 risk factors on executing dredging projects, which

TABLE 2 Background of respondents

Title	No. of respondents
Associate engineer	15
Deputy director of the river management office	1
Director of the river management office	2
Director of the water resources agency	1
Junior engineer	25
Local security chief	2
Section chief of the river management office	6
Section chief of the water resources agency	1
Senior engineer	15
Technician	1
Total	69

were scored on a five-point Likert scale. All collected results were averaged within risk factor categories to generate average scores of each risk factor from all participants. Subsequently, the average scores were plotted on two-dimensional coordinates, so that the risk level of any specific factor could be presented by its coordinates. This risk factor map provided management units with

quantitative information about risk management priorities.

Notably, participants generally believed that weather had the largest risk impact on dredging projects, with an average score of 4.35 points, which was much higher than the average score for any other risk factor. In addition, only the average score of weather exceeded 4 on scale of 1–5, indicating that all engineering personnel agreed on the great impact of weather on projects. The results revealed that the average occurrence (frequency) of all risk factors were relatively close, but weather had the highest with an average score of 3.43 points on a scale of 1–5, revealing that Taiwan's changeable weather poses a considerable risk to dredging projects, particularly during typhoon seasons from July to September, making the smooth completion of projects very difficult.

RIFA distribution map

In this section, the RIFA distribution map were explained in detail. As shown in Figure 4, after the impacts and frequencies of all risk factors on executing dredging projects in the questionnaire were averaged, risk impact was represented on the horizontal axis of the RIFA distribution map (with average score: 2.8 points) and risk frequency was represented on the vertical axis (with average score: 3.4 points), with the midpoint at the average values of impact and frequency. A four-quadrant map, risk control

quadrant, anticipated risk quadrant, risk self-retention quadrant and risk transfer quadrant were created as indicated in Figure 4. Then, the risk factors were plotted one by one on the two-dimensional coordinate map, and the meaning of each quadrant was defined as below.

The first quadrant of high impact–high frequency (HI/HF) was defined as risk control. Risk factors that fell in this quadrant, including, peripheral facilities, weather, geographic location, quality of sand and soil, market supply and demand, public opinion, contractor capability, authority control, contractor control, security personnel and setting of base bidding prices, were the most frequently encountered and most influential risk factors in dredging projects. Reducing the frequency and impact of these risk factors and strengthening the corresponding internal control and emergency response measures are priorities for risk management units.

The second quadrant of low impact and high frequency (LI/HF) was defined as anticipated risk. Although the impact of factors, including pavement, dredging volume, and environmental pollution, in this quadrant was low, their frequency was relatively high. Therefore, precautions and measures had to be taken to reduce or eliminate the risks within this quadrant.

The third quadrant of low impact and low frequency (LI/LF) was defined as risk self-retention. The risk factors that fell in this quadrant, including dredging, environmental

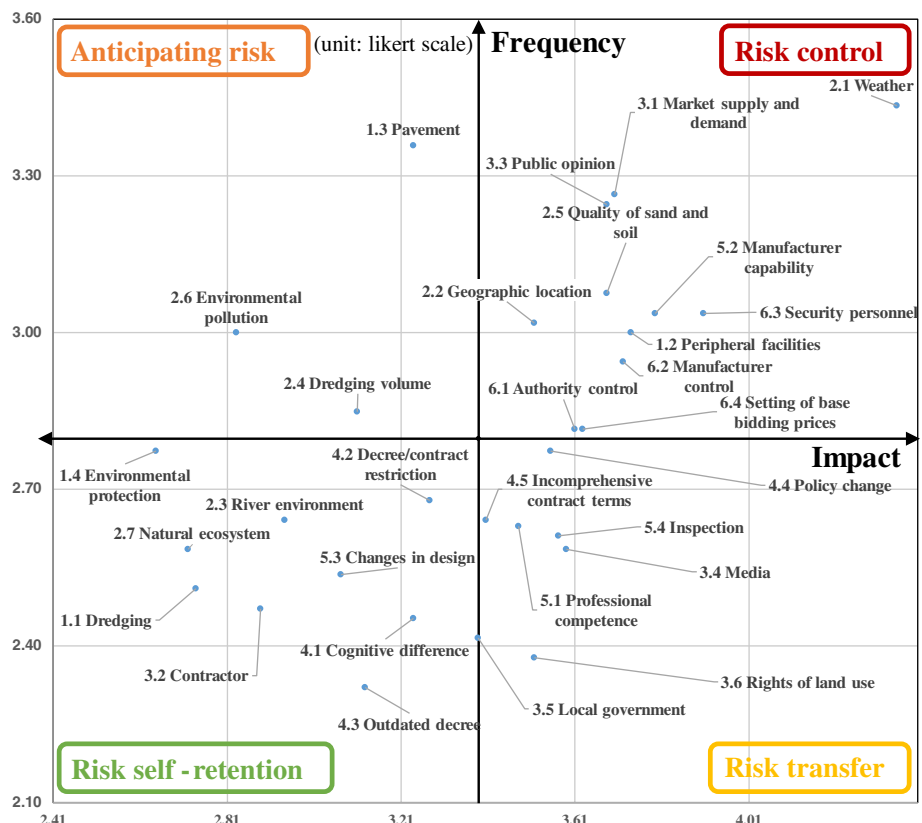


FIGURE 4 Risk impact-frequency analysis for risk response

protection, river environment, natural ecosystem, contractor, local government, cognitive difference, decree/contract restriction, outdated decree, and changes in design, were either within the tolerable range or had risk-processing costs that exceeded any loss that they could cause. Therefore, they would be left untreated.

Finally, the fourth quadrant of high impact and low frequency (HI/LF) was defined as risk transfer. The risk factors that fell in this quadrant, including, media, rights of land use, policy change, incomprehensive contract terms, professional competence, and inspection had a lower frequency than average, but their occurrence was highly likely to shut down the project completely and could negatively affect the reputation of the River Management Offices and the WRA. Therefore, risk factors in this quadrant should either be insured against or handled by relevant businesses, minimising losses to the organisation by transfer of the risks to corresponding professional teams.

5.2.3 | AHP questionnaire results and analysis

According to statistics from the WRA, the total volume of dredging by the 10 River Management Offices in recent 5 years is 213,000 million m³. Figure 5 displays the percentage of total dredged volume of each River Management Office. Thus, to avoid distortions in the results due to variations in dredging engineering experience, the 10 River Management Offices are divided into high- and middle-to-low dredging by whether their total dredged volume is higher or lower than 6% of the total volume of dredging.

The risk factors for conducting river dredging projects were ranked as in Table 3. According to the AHP results, the River Management Offices with a high dredging volume claimed that weather changes (such as related to typhoons and flooding) had the highest impact on the

execution of dredging projects. The requirements of management units and their regulations concerning security personnel, the setting of the base bid price, the market supply and demand for sand and gravel, and the internal control capabilities of contractors of construction bid, peripheral product bid, and income bid also had considerable impacts on dredging projects. This result demonstrated that River Management Offices with a high dredging volume normally attached great importance to risks that are caused by the natural environment and management capabilities.

The analysis of River Management Offices with a medium-to-low dredging volume revealed that the most crucial risk factors were, in descending order, authority control, the setting of bid prices, security personnel, policy changes, and the way of dredging.

5.3 | Comprehensive rankings based on integration of RIFA and AHP

The RIFA quadrant map is a risk assessment graph whose coordinates represent risk impact and frequency. However, some risk factors are often too close to each other to determine their relative importance and priority. The AHP is a method for sorting factors by importance. Some participants were unable to be consistent in comparing risks in terms of impact and frequency when answering the questionnaires. Therefore, in this study, the risk factor ranking that was generated using AHP was integrated with the RIFA quadrant map to yield a comprehensive ranking (Table 4). When a management unit deals with risk factors in the four quadrants, in addition to adopting various risk management techniques, it can rank the risk factors within the quadrant for reference.

The River Management Offices were again grouped into those with high and those with medium-to-low dredging volumes, using the comprehensive ranking that

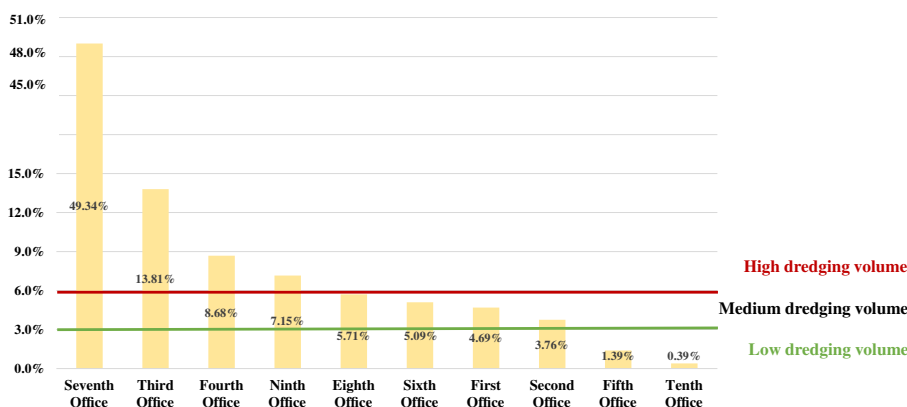


FIGURE 5 Total dredging volume of each River Management Office

TABLE 3 Ranking of risk factors for dredging units in each region by dredging volume

Rank	River management office with high dredging volume	River management office with medium/low dredging volume	National
1	2.1 weather	6.1 authority control	6.3 security personnel
2	6.3 security personnel	6.4 setting of base bidding prices	6.1 authority control
3	6.4 setting of base bidding prices	6.3 security personnel	4.5 incomprehensive contract terms
4	3.1 market supply and demand	4.4 policy change	5.4 inspection
5	6.2 contractor capability	1.1 dredging	4.1 cognitive difference
6	4.5 incomprehensive contract terms	6.2 contractor capability	6.2 contractor capability
7	3.4 media	4.5 incomprehensive contract terms	6.4 setting of base bidding prices
8	2.2 geographic location	3.4 media	2.5 quality of sand and soil
9	2.4 dredging volume	5.2 contractor capability	2.1 weather
10	2.5 quality of sand and soil	5.4 inspection	4.3 outdated decree
11	6.1 authority control	4.2 decree/contract restriction	3.4 media
12	3.3 public opinion	4.3 outdated decree	4.4 policy change
13	5.1 professional competence	2.5 quality of sand and soil	2.2 geographic location
14	3.5 local government	3.3 public opinion	3.1 market supply and demand
15	4.4 policy change	3.5 local government	3.3 public opinion
16	5.4 inspection	1.2 peripheral facilities	2.3 river environment
17	5.2 contractor capability	5.1 professional competence	2.7 natural ecosystem
18	2.3 river environment	3.6 rights of land use	1.3 pavement
19	1.3 pavement	4.1 cognitive difference	5.1 professional competence
20	1.2 peripheral facilities	2.1 weather	3.5 local government
21	3.6 rights of land use	1.3 pavement	3.6 rights of land use
22	3.2 contractor	5.3 changes in design	4.2 decree/contract restriction
23	4.3 outdated decree	2.2 geographic location	2.4 dredging volume
24	5.3 changes in design	2.7 natural ecosystem	2.6 environmental pollution
25	2.6 environmental pollution	3.1 market supply and demand	5.3 changes in design
26	2.7 natural ecosystem	1.4 environmental protection	1.2 peripheral facilities
27	1.4 environmental protection	2.6 environmental pollution	5.2 contractor capability
28	4.1 cognitive difference	2.4 dredging volume	1.4 environmental protection
29	4.2 decree/contract restriction	3.2 contractor	3.2 contractor
30	1.1 dredging	2.3 river environment	1.1 dredging

was obtained from the combination of AHP and the RIFA quadrant map. In the first quadrant, the highest-priority risk factors of the River Management Offices with high and medium-to-low dredging volumes were weather and authority control (control by the relevant authority), respectively.

As shown in Figure 4, the frequency and impact of the weather risk factor in River Management Offices with a high dredging volume greatly exceeded those of other risk factors. Furthermore, the figure demonstrates that the AHP results for the high-dredging-volume River

Management Offices were more consistent with the overall RIFA results.

Results concerning the second quadrant showed that the River Management Offices with a high dredging volume should focus on anticipating the risks that are associated with the volume of sand and gravel that were obtained from dredging whereas those with a medium-to-low dredging volume should first address the risk of pavement construction in their jurisdiction.

The River Management Offices considered lower-ranked risk factors in the third quadrant of risk self-

TABLE 4 Comprehensive rankings obtained by RIFA combined with AHP

Quadrant	Risk factor	High dredging volume		Medium dredging volume	
		Rank	Relative weight	Rank	Relative weight
I (HI/HF)	1.2 peripheral facilities	11	0.0152	8	0.0055
	2.1 weather	1	0.0647	9	0.0039
	2.2 geographic location	6	0.0335	10	0.0030
	2.5 quality of sand and soil	7	0.0318	6	0.0057
	3.1 market supply and demand	4	0.0549	11	0.0025
	3.3 public opinion	9	0.0285	7	0.0057
	5.2 contractor capability	10	0.0191	5	0.0096
	6.1 authority control	8	0.0290	1	0.0174
	6.2 contractor control	5	0.0503	4	0.0115
	6.3 security personnel	2	0.0642	3	0.0148
	6.4 setting of base bidding prices	3	0.0556	2	0.0162
II (LI/HF)	1.3 pavement	2	0.0174	1	0.0032
	2.4 dredging volume	1	0.0330	3	0.0014
	2.6 environmental pollution	3	0.0100	2	0.0022
III (LI/LF)	1.1 dredging	10	0.0055	1	0.0120
	1.4 environmental protection	7	0.0095	8	0.0024
	2.3 river environment	2	0.0184	10	0.0013
	2.7 natural ecosystem	6	0.0096	7	0.0025
	3.2 contractor	3	0.0121	9	0.0014
	3.5 local government	1	0.0259	4	0.0055
	4.1 cognitive difference	8	0.0092	5	0.0044
	4.2 decree/contract restriction	9	0.0083	2	0.0075
	4.3 outdated decree	4	0.0119	3	0.0060
	5.3 changes in design	5	0.0106	6	0.0030
	IV (HI/LF)	3.4 media	2	0.0341	3
3.6 rights of land use		6	0.0139	6	0.0051
4.4 policy change		4	0.0247	1	0.0141
4.5 incomprehensive contract terms		1	0.0427	2	0.0108
5.1 professional competence		3	0.0268	5	0.0054
5.4 inspection		5	0.0195	4	0.0086

retention to be more tolerable. The River Management Offices with a high dredging volume considered that the technology for mining for dredging is simple and has a low risk impact, whereas those with a medium-to-low dredging volume claimed that the risks caused by river environment are the least critical.

The fourth quadrant contained risk factors that should be transferred. River Management Offices with a high dredging volume claimed that incomprehensive contract terms were the primary risk to be transferred, whereas those with a medium-to-low dredging volume

noted that the uncertainty that is caused by policy changes should be the most important transfer target.

6 | DESIGN AND DEVELOPMENT OF DREDGING ENGINEERING KNOWLEDGE BASE

According to the interviews, the personnel from 10 River Management Offices with no experience of undertaking dredging projects consulted experienced seniors and

supervisors whenever they encountered risk events during project execution. However, when the engineers with abundant experience retire, their knowledge and experience may be lost. During the interviews, the participants expressed that such loss of experience was becoming increasingly severe. To preserve such valuable experience, a total of 170 risk events that have been encountered by the personnel and engineers of each River Management Office were collected and recorded from the interviews to form a qualitative risk knowledge base for dredging projects, in the hope of systematically preserving their experiences for future reference.

In this study, MySQL was used as a database management system, and the satisfactory compatibility and graphical user interface (GUI) development capabilities of Python

and MySQL were exploited to create a convenient dredging project knowledge base search system. First, all risk events were classified by RBS risk classification in MySQL into categories of technology, nature, economics and society, laws and contracts, organisation, and management capability. Then, the events were separately classified and numbered according to the risk factor characteristics that were identified by risk classification, supporting the identification of the stage and subprocess in which each risk event may occur in the separated mining–sales operation. Finally, the past methods for handling risk events were recorded. After all risk events were integrated, a user-friendly interface was developed using Python (Figure 6).

To classify properly the 170 risk events and construct a Dredging Engineering Knowledge Base system, all risk

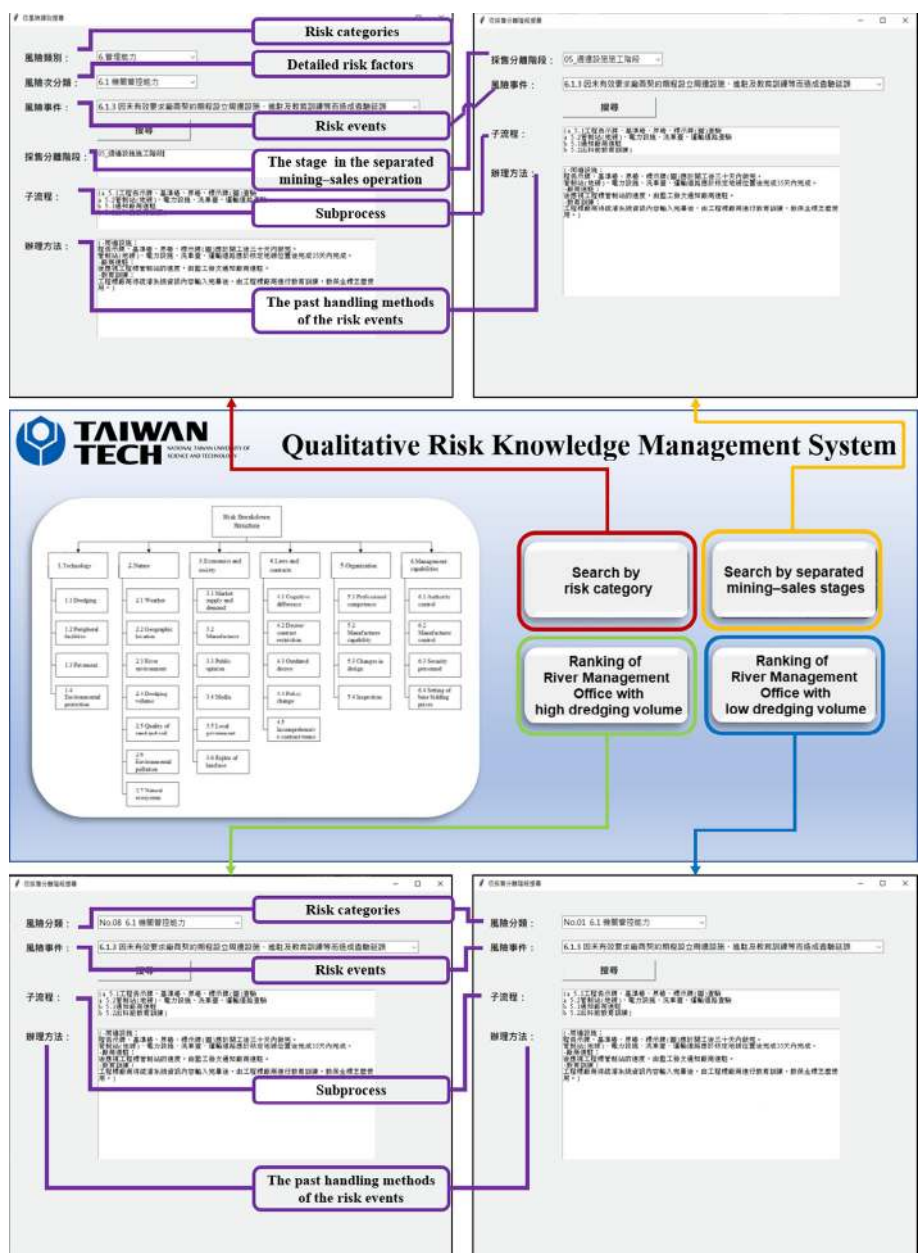


FIGURE 6 Risk knowledge base window for dredging project

events that were obtained in this work were classified into several groups. During the classification, many risk events were observed to occur in multiple stages of the dredging project life cycle. Therefore, there are two types of search methods in the knowledge base to provide a diversified direction of search. One is to search for the risk category of RBS, and the other is to search for life cycle of dredging projects. The knowledge base system was expected to provide valuable risk management of dredging projects. After a risk event list was completed using RBS, the separated mining–sales stages and the sub processes of each risk event to which each risk event belonged were confirmed, and practical solutions for risk events that were extracted during the interviews were stored in the database.

To provide users with a clear and easy way to use the system, the “search by risk category” and “search by separated mining–sales stages” windows were generated for the Dredging Engineering Knowledge Base. Moreover, according to the dredging volumes of the River Management Offices and the high-frequency and high-impact risk events that were previously calculated using the AHP and RIFA, two search windows “high frequency and impact risk ranking of River Management Offices with a high dredging volume” and “high frequency and impact risk ranking of River Management Offices with a medium-to-low dredging volume” were established.

7 | CONCLUSION AND MANAGERIAL IMPLICATIONS

This study used IPA to develop a simple and easily understandable RIFA, whose results are represented in a quadrant map. In this quadrant map, risk factors in the first quadrant required simultaneous reduction of their frequency and impact for risk control. The risk factors in the second quadrant demanded a reduction in frequency (taking risk anticipation measures). Most of the factors in the third quadrant, which had low impact and frequency, usually had a higher handling cost than the loss they could cause. Therefore, risk self-retention was recommended for those factors. Factors in the fourth quadrant, which had high impact and low frequency, should be subject to risk transfer and outsourced to relevant businesses. In this investigation, RIFA was used with AHP for ranking factors to provide a comprehensive assessment.

From the interviews that were conducted with 10 River Management Offices, personnel often consult experienced employees and apply their methods when they encounter risks in projects. As a result, the retirement of those experienced employees could prevent the

smooth operation of dredging projects. To retain the relevant experience of dredging engineering risks at the WRA, 170 risk events that were collected from those interviews were classified using the RBS method. The stages of the separated mining–sale operation and sub processes with which these risk factors belong were identified, and their handling methods were recorded. After the Dredging Engineering Knowledge Base was established using a database management system, a programming language was used to create a search system and a GUI for use by managers to search for relevant knowledge and experience when they encountered risks, helping them to implement the most immediate and appropriate measures to reduce the impact of risks on the project and to improve the smoothness of dredging works, maximising the effectiveness of dredging project risk control.

Unlike most relevant risk analysis studies, this study simultaneously considered the frequency and impact of risks and compared results concerning risk factors to establish a comprehensive ranking thereof. The RIFA was developed to represent the frequency and impact of risks on a quadrant graph. Risk handling is specified on a per-quadrant basis, and this method is easier to implement and understand than previously used risk analysis methods. After risk factors were ranked by AHP, the risk knowledge base was developed to solve the problem that is encountered in most risk analysis studies: in risk management, decisions are typically made by drawing on past experience and knowledge.

In the construction of a risk knowledge base, this study revealed that River Management Offices have different methods for dealing with risks because of differences in geographical environment, climate, and customs. Hence, the developed knowledge base may be insufficient to deal with all risk events. This investigation suggests that each River Management Office can develop its own risk knowledge base to process and preserve experiences of risk mitigation. In this work, a risk analysis of dredging projects was completed. Future studies could perform risk analyses in other areas of public engineering (such as offshore wind power and mass rapid transit construction projects) based on the research methods and framework herein. Compared with previously presented analytical methods, this framework supports the more comprehensive consideration of risk, more precise risk ranking and more practical recommendations.

Currently, the GUI of the knowledge base with the pull-down menu design enables users to identify risk events efficiently. The Dredging Engineering Knowledge Base and its search system that were established in this study were based on risk events and handling methods

that were identified in interviews with personnel from 10 River Management Offices. The main distinctive contribution of this study allows the management unit to ensure knowledge of risk mitigation and remedial measures can be appropriately reserved in the flood risk management system. Because many risk events cannot be solved using any practical method, future studies should focus on improving the method and updating risk events that are encountered by each River Management Office.

Future research can also involve the design of a feedback mechanism for use in the risk knowledge base system to enable the personnel of River Management Offices to provide suggestions for revisions of the knowledge base after review. The methods for handling all risk events should be continuously revised to provide multiple solutions for the same risk event to management units in different regions to enable them to respond most appropriately and make optimal decisions under local conditions. Another research direction is to upgrade the knowledge base search system to a chatbot so as to render it more convenient for personnel in charge to find related events and corresponding solutions of dredging project operations.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Science and Technology, Taiwan, for financially supporting this research under contract 108-2221-E-011-003-MY3.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Jui-Sheng Chou  <https://orcid.org/0000-0002-8372-9934>

REFERENCES

- Anjasmoro, B., Suharyanto, & Sangkawati, S. (2017). Priority analysis of small dams construction using cluster analysis, AHP and weighted average method case study: Small dams in Semarang district. *Procedia Engineering*, 171, 1514–1525.
- Chen, Z., Li, H., Ren, H., Xu, Q., & Hong, J. (2011). A total environmental risk assessment model for international hub airports. *International Journal of Project Management*, 29(7), 856–866.
- Ding, L. Y., Zhong, B. T., Wu, S., & Luo, H. B. (2016). Construction risk knowledge management in BIM using ontology and semantic web technology. *Safety Science*, 87, 202–213.
- Dolinsky, A. L. (1991). Considering the competition in strategy development: An extension of importance-performance analysis. *Journal of Health Care Marketing*, 11(1), 31–36.
- Duddu, V. R., Kukkapalli, V. M., & Pulugurtha, S. S. (2019). Crash risk factors associated with injury severity of teen drivers. *IATSS Research*, 43(1), 37–43.
- El-Sayegh, S. M., & Mansour, M. H. (2015). Risk assessment and allocation in highway construction projects in the UAE. *Journal of Management in Engineering*, 31(6), 04015004.
- Gerring, J. (2007). *Case study research: Principles and practices*, Cambridge, UK: Cambridge University Press.
- Ghimire, L. P., & Kim, Y. (2018). An analysis on barriers to renewable energy development in the context of Nepal using AHP. *Renewable Energy*, 129, 446–456.
- Ghosh, S., & Jintanapakanont, J. (2004). Identifying and assessing the critical risk factors in an underground rail project in Thailand: A factor analysis approach. *International Journal of Project Management*, 22(8), 633–643.
- Hallowell, M., Esmaeili, B., & Chinowsky, P. (2011). Safety risk interactions among highway construction work tasks. *Construction Management and Economics*, 29(4), 417–429.
- Han, S. H., Kim, D. Y., Kim, H., & Jang, W.-S. (2008). A web-based integrated system for international project risk management. *Automation in Construction*, 17(3), 342–356.
- Hosny, H. E., Ibrahim, A. H., & Fraig, R. F. (2018). Risk management framework for continuous flight auger piles construction in Egypt. *Alexandria Engineering Journal*, 57(4), 2667–2677.
- Huang, C.-C., Chu, P.-Y., & Chiang, Y.-H. (2008). A fuzzy AHP application in government-sponsored R&D project selection. *Omega*, 36(6), 1038–1052.
- Karasan, A., Ilbahar, E., Cebi, S., & Kahraman, C. (2018). A new risk assessment approach: Safety and critical effect analysis (SCEA) and its extension with Pythagorean fuzzy sets. *Safety Science*, 108, 173–187.
- Karthiyayini, N., Rajendran, C., & Kumaravel, M. (2018). Importance-performance analysis (IPA) for testing – And calibration – Laboratories in India. *Benchmarking: An International Journal*, 25(4), 1232–1244.
- Khaloie, H., Abdollahi, A., Rashidinejad, M., & Siano, P. (2019). Risk-based probabilistic-possibilistic self-scheduling considering high-impact low-probability events uncertainty. *International Journal of Electrical Power & Energy Systems*, 110, 598–612.
- Krueger, R. A., & Casey, M. A. (2000). *Focus groups: A practical guide for applied research*, Newbury Park, CA: SAGE.
- Lai, L. S. L., & To, W. M. (2010). Importance-performance analysis for public management decision making: An empirical study of China's Macao special administrative region. *Management Decision*, 48(2), 277–295.
- Lee, J., & Lee, H. (2015). Deriving strategic priority of policies for creative tourism industry in Korea using AHP. *Procedia Computer Science*, 55, 479–484.
- Liberatore, M. J. (1987). An extension of the analytic hierarchy process for industrial R&D project selection and resource allocation. *IEEE Transactions on Engineering Management*, EM-34(1), 12–18.
- Liebowitz, J. (1999). Key ingredients to the success of an organization's knowledge management strategy. *Knowledge and Process Management*, 6(1), 37–40.
- Martilla, J. A., & James, J. C. (1977). Importance-performance analysis. *Journal of Marketing*, 41(1), 77–79.

- Medina-Muñoz, D. R., & Medina-Muñoz, R. D. (2014). The attractiveness of wellness destinations: An importance–performance–satisfaction approach. *International Journal of Tourism Research, 16*(6), 521–533.
- Miller, R., & Lessard, D. (2001). Understanding and managing risks in large engineering projects. *International Journal of Project Management, 19*(8), 437–443.
- Mockler, R. J., & Dologite, D. G. (1988). Developing knowledge-based systems for strategic corporate planning. *Long Range Planning, 21*(1), 97–102.
- Muriana, C., & Vizzini, G. (2017). Project risk management: A deterministic quantitative technique for assessment and mitigation. *International Journal of Project Management, 35*(3), 320–340.
- Niehaves, B., Plattfaut, R., & Becker, J. (2013). Business process management capabilities in local governments: A multi-method study. *Government Information Quarterly, 30*(3), 217–225.
- Palmer, A., & O'Neill, M. A. (2004). Importance-performance analysis: A useful tool for directing continuous quality improvement in higher education. *Quality Assurance in Education, 12*(1), 39–52.
- Perera, B. A. K. S., Rameezdeen, R., Chileshe, N., & Hosseini, M. R. (2014). Enhancing the effectiveness of risk management practices in Sri Lankan road construction projects: A Delphi approach. *International Journal of Construction Management, 14*(1), 1–14.
- Rodriguez-Valencia, A., Rosas-Satizabal, D., & Paris, D. (2019). Importance-performance analysis in public transportation: Methodological revision for practical implementation. *Transportation Research Record, 2673*(2), 710–723.
- Rubin, H. J., & Rubin, I. S. (2005). *Qualitative interviewing: The art of hearing data*. Thousand Oaks, CA: Sage.
- Saaty, T. L. (1994). Highlights and critical points in the theory and application of the analytic hierarchy process. *European Journal of Operational Research, 74*(3), 426–447.
- Seo, J. W., & Choi, H. H. (2008). Risk-based safety impact assessment methodology for underground construction projects in Korea. *Journal of Construction Engineering and Management, 134*(1), 72–81.
- Serpella, A. F., Ferrada, X., Howard, R., & Rubio, L. (2014). Risk Management in Construction Projects: A knowledge-based approach. *Procedia - Social and Behavioral Sciences, 119*, 653–662.
- Tserng, H. P., Yin, S. Y. L., Dzeng, R. J., Wou, B., Tsai, M. D., & Chen, W. Y. (2009). A study of ontology-based risk management framework of construction projects through project life cycle. *Automation in Construction, 18*(7), 994–1008.
- Unutmaz Durmuşoğlu, Z. D. (2018). Assessment of techno-entrepreneurship projects by using analytical hierarchy process (AHP). *Technology in Society, 54*, 41–46.
- Wiess, R. S. (1994). *Learning from strangers: The art and method of qualitative interview studies*. New York: The Free Press.
- Willumsen, P., Oehmen, J., Stingl, V., & Geraldi, J. (2019). Value creation through project risk management. *International Journal of Project Management, 37*(5), 731–749.
- Xia, N., Zou, P. X. W., Griffin, M. A., Wang, X., & Zhong, R. (2018). Towards integrating construction risk management and stakeholder management: A systematic literature review and future research agendas. *International Journal of Project Management, 36*(5), 701–715.
- Yanagisawa, K., Imamura, F., Sakakiyama, T., Annaka, T., Takeda, T., & Shuto, N. (2007). Tsunami assessment for risk Management at Nuclear Power Facilities in Japan. *Pure and Applied Geophysics, 164*(2), 565–576.
- Zhu, M., Pan, H., Miao, W., & He, J. (2017). Study on the risk Management of Dredging Engineering. *Journal of Scientific and Engineering Research, 4*(4), 86–90.

How to cite this article: Chou J-S, Chiu Y-C. Identifying critical risk factors and responses of river dredging projects for knowledge management within organisation. *J Flood Risk Management*. 2021;14:e12690. <https://doi.org/10.1111/jfr3.12690>