

Risk assessment by integrating interpretive structural modeling and Bayesian network, case of offshore pipeline project



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ABSTRACT

The sound development of marine resource usage relies on a strong maritime engineering industry. The perilous marine environment poses the highest risk to all maritime work. It is therefore imperative to reduce the risk associated with maritime work by using some analytical methods other than engineering techniques. This study addresses this issue by using an integrated interpretive structure modeling (ISM) and Bayesian network (BN) approach in a risk assessment context. Mitigating or managing maritime risk relies primarily on domain expert experience and knowledge. ISM can be used to incorporate expert knowledge in a systematic manner and helps to impose order and direction on complex relationships that exist among system elements. Working with experts, this research used ISM to clearly specify an engineering risk factor relationship represented by a cause–effect diagram, which forms the structure of the BN. The expert subjective judgments were further transformed into a prior and conditional probability set to be embedded in the BN. We used the BN to evaluate the risks of two offshore pipeline projects in Taiwan. The results indicated that the BN can provide explicit risk information to support better project management.

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1. Introduction

Rapidly increasing populations have stimulated economic activities over the last few decades, gradually depleting land resources and energy. Consequently, certain human activities have moved from the land to the sea to explore marine resources to support economic development. For example, countries have exploited offshore natural gas and oil resources and near-shore wind-farm installations. Maritime engineering is necessary to the success of offshore development projects. However, because of the highly uncertain ocean working environment, the probability of maritime engineering project failure is high. Using risk assessment to improve maritime engineering technology is a reasonable approach to managing this problem.

Risk is generally understood as the possibility of human casualties or property damage caused by an event. Therefore, the risk of an event includes the number of casualties or extent of damage and the frequency of occurrence [1–3]. A similar concept

of risk is described by the British Standards Institute [4], which defines the risk as “the combination of the likelihood and consequence(s) of a specified hazardous event.” The risk management guidelines of the International Organization for Standardization (ISO) 31000 [5] include a broader description of risk: “Organizations of all types and sizes face internal and external factors and influences that make it uncertain whether and when they will achieve their objectives. The effect this uncertainty has on an organization's objectives is ‘risk’.”

Maritime engineering projects can be compared to organizations, as indicated in ISO 31000, because they both face uncertainty when attempting to achieve their objectives. Risk assessment is a risk management process that is crucial to mitigating the impact of uncertain factors. Risk assessment is used to measure the value of risk and identify the effects of hazardous events on an organization or project by using various analytical methods, including qualitative, quantitative, model-based, and knowledge-based tools. The ultimate risk assessment goal is to facilitate decision making in specific situations that are recognized threats to organizational and project management. According to ISO 31000, risk assessment integrates the following three processes, which were used as the research framework of this study:

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- Risk identification: for a sound engineering project, it is important to broadly identify sources of risk, reasons for the risk, and risk effects at the beginning of a project.
- Risk analysis: based on risk identification, risk analysis during an engineering project should describe the characteristics of risk, determine their consequences, and the likelihood that they will occur by using the appropriate methods, which can be qualitative, semi-quantitative, quantitative, or a combination thereof.
- Risk evaluation: the results of risk analysis can be used to support better risk evaluation to make decisions on the priority of risk treatments by comparing the levels of risk found during the analysis process.

Engineering project managers have recently adopted risk control techniques to improve project success rates [6]. A successful engineering project depends on strong engineering technology and on knowing how to deal with the risks caused by uncertain factors throughout a project. Simm and Camilleri [7] argued that risk management can provide assistance to engineering projects in the following three areas:

- Identifying factors that influence project success.
- Focusing on the most hazardous factors based on risk priority levels.
- Balancing the costs and benefits of risk treatments.

Artificial intelligence (AI) can manage problems that are characterized by uncertainty or insufficient data [8]. It is difficult to quantify the uncertainty of risk during risk analysis by using statistical methods when no data or insufficient data exist. In this situation, some AI techniques may complement the requirements of risk analysis. A Bayesian network (BN) is an uncertain reasoning method that uses probabilities. The probabilities in a BN can either be acquired from data analyses or assigned by domain experts [9]. Therefore, the BN method is suitable for risk analyses of maritime engineering projects where domain experts, but not data, are available.

This study adopted the risk assessment procedures outlined in ISO 31000 to explore the risk associated with a maritime engineering project—an offshore pipeline. Risk identification was conducted to confirm the factors that are critical to an offshore pipeline project by using a literature review and expert interviews. A risk analysis using the BN method was then conducted. A prerequisite for building a BN is to formulate a causal network structure to specify the interactions between the critical factors in an offshore pipeline project. This study used an interpretive structural modeling (ISM) approach to systematically acquire a hierarchical network from experts to facilitate BN structure building. The experts were then asked to assign a set of probabilities based on their experience to finalize a complete BN. A risk evaluation based on the BN was then performed for two offshore pipeline cases to support better risk assessment in related maritime engineering projects.

- Allows expert opinions and knowledge to be incorporated based on a systematic method.
- Provides sufficient opportunities for correcting opinions.
- Does not require a large number of operations to process systems with 10–15 factors, and can conveniently be applied to real life cases.

Malone [13] proposed that the basic concept of ISM is to search for prior and subsequent contextual relationships related to element sets to allow individuals and groups to understand complex system states, and thereby create action plans to solve problems. Because ISM can be used to describe complex relationships between factors, it is also commonly used to analyze crucial factors that influence standard specifications. Ravi and Shankar [14] proposed that the advantages of ISM include that it can be used to explore the mutual influence between factors and to clearly list increases or decreases in these influential relationships. They used ISM to analyze a supply chain and explore the interactive relationships between obstacles in reverse logistics. Hsiao and Liu [15] attempted to find product lines that responded to market demand, and designed an ISM model to search for products that met market demand. Bolanos et al. [16] proposed that, in complex situations, ISM can effectively connect the subjective perceptions of participants, and used ISM in group decision-making to clearly present individual subjective perceptions. Faisal et al. [17] used ISM to understand the influences of various performance enablers in a supply chain, and to analyze an effective supply chain risk mitigation strategy.

Based on these descriptions, ISM has been used in several fields and is a reliable tool for solving a series of complex problems. This method can be used to clarify problem structures and establish levels to help describe problem structures and factor priorities. The general steps of the ISM operating procedure are described as follows [18]:

- Use a survey to confirm the related factors;
- Establish the hierarchical relationships between the factors and develop a structural self-interaction matrix (SSIM) for the factors;
- Convert the SSIM into a binary matrix, called a reachability matrix, and evaluate the transitivity of the matrix (for example, if A and B are related and B and C are related, then A and C are related);

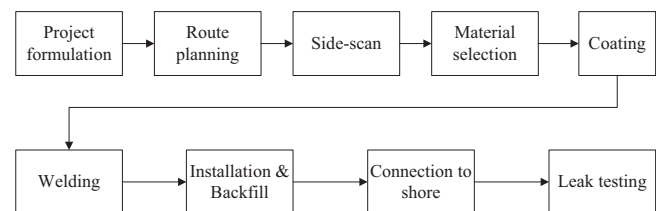


Fig. 1. Operational flow of offshore pipeline projects suggested by the experts.

2. Research methodology

2.1. Interpretive structural modeling

Warfield [10] developed ISM as a computer-aided method. Mandal and Deshmukh [11] proposed using ISM as a method to confirm and describe relationships between specific factors, and to explain problems. ISM uses interviewed groups to describe ordinal relationships among complex factors. The advantages of ISM include the following [12]:

Table 1

Risk factors and the corresponding symbols.

Factor	Symbol	Factor	Symbol
Project formulation	S1	Project permission	S8
Route planning	S2	Anticorrosive coating	S9
Side-scan	S3	Pipeline welding	S10
Material selection	S4	Equipment operation	S11
Equipment testing	S5	Pipeline installation and backfill	S12
Background knowledge	S6	Pipeline connection to shore	S13
Experience	S7	Leak testing	S14

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