KNOWLEDGE MANAGEMENT SYSTEM AS AN EFFICIENT AND SUSTAINABLE STRATEGY TO MINIMIZE UNCERTAINTY IN THE PROCESS OF RISK ASSESSMENT

Jiaqi Sun *

* School of International Business, Shandong Vocational University of Foreign Affairs, Weihai, China;
Shandong SMCTS Corporate Management Consulting Co., Ltd., Shandong, China
Contact details: School of International Business, Shandong Vocational University of Foreign Affairs, 788 Changjiang Road, Rushan, Weihai, Shandong 264504, China

How to cite this paper: Sun, J. (2024). Knowledge management system as an efficient and sustainable strategy to minimize uncertainty in the process of risk assessment. *Corporate Governance and Sustainability Review, 8*(2), 8–23. https://doi.org/10.22495/cgsrv8i2p1

ISSN Online: 2519-898X
ISSN Print: 2519-8971

Received: 01.07.2023
Accepted: 11.07.2024

JEL Classification: C18, D81, D83, K32, Q01
DOI: 10.22495/cgsrv8i2p1

Abstract

Risk assessors could adopt qualitative, semi-quantitative, or quantitative approaches to analyze various risks; the combination of these approaches alleviates the shortcomings of risk assessment techniques, namely uncertainty, knowledge dimension, and time dynamics when techniques are used alone. The knowledge dimension plays a pivotal role in these shortcomings, as knowledge reduces uncertainty (United States Environmental Protection Agency [EPA], n.d.-a) and the timely knowledge update of global trends and emerging risks is expected to resolve the issue of time dynamics (another cause of uncertainty) by reassessing risks and characterizing risk data over a time interval (Wassénius & Crona, 2022). However, substantial research and development are required to generate adequate modeling and analytical methods to deal with different and complex systems. Based on the literature review and industry best practices, the study develops a risk assessment knowledge management system framework that focuses on the root of the shortcomings of risk assessment techniques, namely the knowledge dimension; this strategy is efficient and sustainable by indirectly addressing the unresolved issues of uncertainty and time dynamics through the knowledge dimension. The conceptual framework minimizes the uncertainty (the root of risk) in the decision-making process of selecting the appropriate risk assessment tools and effectively implementing them.

Keywords: Knowledge Management, Operational Risk, Uncertainty, Risk Assessment, ESG, Performance Measurement Management Control

Authors' individual contribution: The Author is responsible for all the contributions to the paper according to CRediT (Contributor Roles Taxonomy) standards.

Declaration of conflicting interests: The Author declares that there is no conflict of interest.

1. INTRODUCTION

As the critical component of a risk management process, the concept and definition of risk assessment were first systematically formulated in 1983, according to the United States National Research Council Committee on Risk Assessment of Hazardous Air Pollutants. Risk assessment methodologies and techniques have been widely adopted across industries and evolved with changing global trends, such as population, economic development, and technological advancement. To date, financial services and safety-related risk management practices are the two most mature fields with well-established risk assessment processes and management systems in place (Jain et al., 2020).

Emerging systematic risks, such as the COVID-19 global pandemic, reveal that many organizations are not well prepared to assess and manage risk

(Jain et al., 2020). With changing conditions, organizations are expected to reassess known risks while continually researching and developing innovative solutions against emerging risks, for example, the evidence-based risk assessment methodology proposed by Hoffmann et al. (2022). Literature review uncovers the research gaps in knowledge dimension and time dynamics, which have constantly posed challenges to organizations and risk assessors due to associated uncertainty and data variability issues (United States Environmental Protection Agency [EPA], n.d.-a); knowledge is the main engine of dealing with information uncertainty (Mahdi et al., 2020), which is the third parameter in three-dimensional risk matrices (Bao et al., 2022); these issues, if not addressed, could hurt the effectiveness of techniques used to assess and control risk. Hence, the study poses the following research questions:

RQ1: What kind of relationships exist among uncertainty, knowledge dimension, and time dynamics?

RQ2: Is there a more efficient and sustainable solution to minimize uncertainty in the process of risk assessment?

As adopted by modern risk management frameworks, such as the Committee of Sponsoring Organizations of the Treadway Commission (COSO) and Basel III, the combination of qualitative judgment and quantitative models could be an effective means to reduce the issues of uncertainty, knowledge dimension, and time dynamics, among other shortcomings of risk assessment techniques. However, the literature review indicates that uncertainty remains a critical, unresolved issue in risk assessment, which requires substantial research and development to generate adequate modeling and analytical methods to deal with different and complex systems, such as critical infrastructural systems (Aven, 2016).

To fill the research gaps of uncertainty, the study aims to identify an efficient and sustainable strategy to minimize uncertainty and subsequently risk. By reviewing literature in the space of operational, strategic, and hazard risks, the study adopts the approach of conceptual frameworks to design innovative solutions to unresolved issues in the process of risk assessment based on literature review and industry best practices. As a result, the study develops the conceptual framework of a risk assessment knowledge management system, which motivates staff to continually learn and develop innovative risk assessment solutions in line with changing global trends, emerging risks, and evolving methodologies and techniques; the conceptual framework is expected to minimize uncertainty in risk assessment by addressing the two causes of uncertainty, namely knowledge dimension and time dynamics. This conceptual framework lays the foundation of a knowledge management system software and applies to any type of system.

The rest of the study is structured as follows. Section 2 provides the literature review of risk assessment methodologies and techniques and their evolvement trends, categories, characteristics, and selection criteria. Section 3 describes the research methodology and the underlying approaches. As the result of the study, Section 4 develops the conceptual framework of the risk assessment knowledge management system and explains how it minimizes the issue of uncertainty over time. Section 5 continues to discuss the key results. In Section 6, the study concludes by highlighting the key insights of the risk assessment process, which underline the strategic rationale behind the risk assessment knowledge management system framework, and recommending the areas for future research.

2. LITERATURE REVIEW

The study reviews the literature on processes, methodologies, and techniques used to identify, analyze, and evaluate risks; they form the basis of literary discussion and research illustration. Because risk assessment and management are well-researched topics across industries, the study prioritizes operational, strategic, and hazard risks because of the need for further research and development. This section reviews the primary risk assessment methodologies and their evolvement trends and compares various assessment methods, techniques, and selection criteria. The key findings identify research gaps and form research questions.

2.1. Primary risk assessment methodologies and evolvement trends

As part of the risk management process, risk assessment frameworks are the methodology used to assess risks and select the right measures to minimize risks; risk professionals are required to treat risks from the perspective of enterprise-wide risk management (ERM). Quantitative risk assessment calculates algorithms to discretely and objectively allocate value to assets, threats, vulnerabilities, and confidence levels. In comparison, qualitative risk assessment covers the same elements but are more subjective and general in indicating the significant risk areas to be addressed (Evrin, 2021).

Risk assessment evaluates how incidents could potentially be an obstacle to achieving business objectives. The assessment outcome assists enterprises with selecting appropriate risk control measures to reduce the incident cost in line with the organization's risk tolerance threshold. The COSO states that two parameters, namely probability (likelihood) and consequence (impact), are the essential part of the risk assessment equation (Mestchian et al., 2005). The risk assessment process identifies, analyses, and evaluates the probability (likelihood or frequency) and consequence (impact or severity[1]) of risks across the organization, which is often the fundamental part of the ERM program or system, such as occupational health, safety, environment, and quality (OHSEQ) risk management.

International risk management standards, such as ISO 31000, develop the risk management principles, framework, and process and outline a generic risk management program. Based on international standards, organizations must choose

[1] Severity and frequency are used in modern operational risk management (ORM) practices, whereas impact and likelihood are the terms of traditional ORM.

their risk assessment process that consists of risk identification, analysis, and evaluation steps.

The study reviewed methodologies and techniques in the space of operational, strategic, and hazard risk assessment, all of which have a financial impact on enterprises.

1) Operational risks result from businesses' operational issues, such as new products, services, and technologies. They could significantly affect an organization's overall risk profile (Mohammed & Sykes, 2012). Operational risk management (ORM) focuses on the organization's internal risks, such as occupational health and safety.

2) Strategic risks cover external risks and affect the implementation of risk management strategies. As strategic risk is not preventable, risk managers should correctly identify and mitigate the impact of incidents (Kaplan & Mikes, 2012).

3) Hazard risks are often driven by exogenous factors that impact the environment where organizations operate. Insurance and appropriate contingency plans mitigate some of the hazard risks (Mohammed & Sykes, 2012). As the OHSEQ risk management covers aspects related to the people, process, and system of the organization, OHSEQ hazard risks are also part of operational risks, for example, external public health and internal occupational health are interrelated risks (Sun, 2022).

As every organization has a unique portfolio of risks, they should tailor the risk management processes to the risk categories mentioned above. While a compliance or rules-based approach is effective for managing preventable risks, it appears to be less effective for strategic or external risks, as open and explicit risk discussions are essential parts of the risk assessment process.

Due to the correlation among risks, a specific risk could be part of two or more risk categories and overseen by more than one manager. Organizations also have different definitions of risk, for example, some legal and hazard risks fall under operational risks. Sun and Van Rooyen (2011) state that commercial banks in South Africa generally are exposed to four risk categories, namely interest rate, market, credit, and operational risks. However, Beers (2022) suggests that there is no one-size-fits-all methodology for risk assessment and many organizations rely on experience and reasonable approximation; an effective risk assessment process must adapt or cater to specific danger; risk identification should lead to effective analysis, which then informs corporate governance.

ORM has shifted its focus from expected loss assessment to risk-based strategic decision-making. Although the key stages of risk management frameworks and processes have remained the same, the methods and procedures at each stage have evolved. For example, risk assessment has shifted from one risk per risk type at a time to multiple risk events across risk classes simultaneously.

In service-oriented industry sectors, such as banks, operational risks have become an independent discipline since early 2000 after noticing the risks associated with operations or staff activities for a long time. Eceiza et al. (2020) expect ORM in the financial services industry to shift from risk reporting to understanding the true level of risk and digitizing operations.

Root cause analysis is the critical step in ensuring the effectiveness of risk assessment, as it resolves an issue by preventing root causes from occurring; this is also one of the factors that enabled the update of ISO 9001 and 14001 management system standards in 2015 to become preventative and proactive risk management guidelines.

Typically, the trail of risk management starts with risk assessment initiated by business leadership, which is the precursor of enterprise strategic planning (Sun, 2018). As business environments and situations change, business leaders are expected to review their risk assessment processes to ensure accuracy and relevance.

Neither are risk assessment processes expected to be perfect nor too complicated; they should cover the basics and continue to improve until they become both effective and efficient (Martins et al., 2021). Aven and Flage (2018) propose a method of risk perspectives for risk assessment, which goes beyond the standard technique of risk matrix and associated probability and consequence estimation.

Organizations are expected to deploy dynamic and flexible risk management practices to navigate an unpredictable future when change comes quickly. The vulnerability to global systematic risk events, such as the COVID-19 pandemic, has unveiled that many companies are not well-prepared for risk events that have profound, long-lasting impacts. Big data analytics and natural language processing technologies empower organizations to improve the precision of risk assessment results through the effective, predictive detection of risk and the real-time digital dashboards of internal and market intelligence (Jain et al., 2020).

From a holistic risk management perspective, Jones and Jarvis (2020) recommend revising the risk assessment methodology to be more comprehensive. Risk assessors are expected to know the environment where the organization operates and related policies, procedures, and past assessments in both their home country and international operations. This practice aligns with the portfolio approach to risk assessment by incorporating the interrelationship among risks.

Concerning the relationship between knowledge and uncertainty, Bratianu and Bolisani (2015) present knowledge strategies as an integrated approach to managing uncertainty and creating desirable futures in business environments. Akhavan et al. (2018) confirm that an adequate knowledge acquisition process leads to accurate knowledge in a knowledge management system (namely, reduced uncertainty) and improves the decision-making process; their study proposes a method for evaluating the reliability of a tacit knowledge acquisition model used to assess and prioritize risks. Mahdi et al. (2020) find that knowledge management is one of the main engines to assist managers in the organization with processing information uncertainty or dealing with the issue of the lack of information.

Given the interconnection and spill-over effect among risks, KPMG (2019) develops a dynamic risk assessment methodology by expanding the traditional two-dimensional risk matrix (likelihood and impact) into four dimensions, which adds the velocity and contagion elements and incorporates global trends as the qualitative supplement; this new development addresses the time dynamics issue of risk assessment.

Another innovation surrounding the risk matrix technique is a three-dimensional measure in which knowledge is the third element in addition to the traditional two-dimensional matrix (Bao et al., 2022). This development work addresses the knowledge dimension issue of risk assessment. A risk matrix could be treated as either a methodology or a specific technique regarding risk assessment, as a variety of matrix-based techniques are in place.

In the space of environmental and health risk management, the United States EPA (n.d.-a) recommends a tiered approach to risk exposure assessment when exposure evaluation involves different levels of complexity in terms of data variability and uncertainty; the approach starts with a simple assessment and determines whether further evaluation of uncertainty and variability is necessary. However, data variability is not reducible but characterizable quantitatively, whereas uncertainty is reducible because of the lack of knowledge of exposure factors or the use of non-precise measurement methods. Both qualitative (e.g., discussions) and quantitative (e.g., sensitivity analysis and Monte Carlo simulation) approaches could reduce uncertainty; qualitative approaches require the information or knowledge on uncertainty level, data gaps, and any subjective decisions or instances of professional judgment, whereas quantitative approaches require more and better data to enhance the precision of assessment results.

Evidence-based risk assessment methodology, especially systematic review, has seen increased adoption in environmental and health risk management to improve the transparency, comprehensiveness, and objectivity in the process of gathering, assessing, and synthesizing evidence to answer research questions. Hoffmann et al. (2022) believe that this methodology contributes to the identification and assessment of uncertainties and demonstrates the effect of assessing the chemical risk to human health.

With emerging analytics technologies, such as machine learning, users with limited technical knowledge in risk management could easily implement modern, automated risk assessment measures. The accuracy of risk assessment improves due to the access to large data samples. Innovative solutions based on emerging technologies will gain more research and development interests in the future.

2.2. Risk assessment categories, characteristics, use cases, and selection criteria

Under modern ORM, the key differences between risk assessment and risk measurement are data type and how parameters are derived. Risk measurement is often more reliable than risk assessment when there is an adequate amount of hard data[2]. This study treats risk measurement as one type of risk assessment that combines hard and soft data.

In general, the banking sector implements the most mature risk management approach, followed by industries where safety is a paramount issue, such as oil and gas, advanced manufacturing, and pharmaceutical sectors (Jain et al., 2020). Most risk assessment techniques derive from the risk matrix methodology or technique, which consists of probability and consequence; exposure and vulnerability parameters could be added to the risk matrix when it comes to environmental, health, disaster, and cybersecurity risk management. Other risk assessment techniques are more quantitative than risk matrices, such as crime risk assessment mechanisms (a vector function) and traffic accident prediction models (regression analysis). Simulation and modeling techniques, such as surrogate safety assessment and neuron networks, formulate sophisticated quantitative risk assessment models.

Single-value risk scores have been the most-used risk assessment approach in, for example, regulatory risk assessment, whereas the probabilistic risk assessment approach is key to generating robust assessment results, especially in environmental risk management. The preference for simple methods results from factors, such as the lack of training in statistical methodology and the inertia in regulatory systems, among others; the conventions of the past are likely to be the barrier to effectively assessing future risk events, such as climate change (Moe et al., 2022).

The knowledge of the categories of risk methodologies and techniques, characteristics (qualitative, semi-quantitative, and quantitative), and their use cases in the process of risk assessment enhances the understanding of which tools are the most effective in assessing the risk in certain use cases. The following reviews the characteristics, use cases, and selection criteria of different categories of risk assessment methodologies and techniques.

2.2.1. Risk assessment methodologies

While the taxonomy of various risk assessment methods differs, their features are fundamentally the same, and primary risk assessment approaches share similar elements, such as hazard, frequency, severity, exposure, and vulnerability. The drawbacks of risk assessment mainly result from the subjective estimate of risk value (the UK National Cyber Security Centre, 2023). The results section of the study addresses this issue regarding the uncertainty in decision-making.

An enterprise's risk assessment methodology is usually composed of both qualitative and quantitative techniques. Qualitative techniques are appropriate when risks are not quantifiable or when sufficiently credible data to conduct quantitative analysis are either not practicably available or data acquisition or analysis is not cost-effective. Quantitative techniques are typically more precise and used in more complex activities to supplement qualitative techniques. The combined qualitative and quantitative approaches improve the accuracy of assessment results and cost-effectively enrich the quantitative measures with qualitative descriptions. Moreover, semi-quantitative techniques take the qualitative approach a step further by attributing values or multipliers to either the probability or consequence component of the risk assessment equation. Business units should choose techniques that meet the requirements of precision and culture. However, business unit-level practices should facilitate the enterprise-wide risk assessment work, according to the COSO.

[2] Hard data are empirical data collected through a robust process, while soft data are empirical data collected through some other reliable processes.

Modern risk management frameworks, such as Basel III, COSO, MIL-STD-882, and Solvency II, combine subjective and data-driven risk assessment approaches; this integrated approach is necessary for assessing low-likelihood high-impact incidents, such as the collapse of the World Trade Center and the Tsunami natural disaster (Mestchian et al., 2005). High-impact incidents should use quantitative or semi-quantitative risk assessment methods (Cioca et al., 2010).

In the process of risk assessment, risk analysis is a scientific technique used to analyze incidents' frequency and severity, after which risk evaluation generates a value based on risk analysis results. At high levels of decision-making, risk evaluation incorporates various interrelated factors, such as public risk tolerance, cost-and-benefit trade-off, socio-politics, and ethics (Mullai, 2006). Various root cause analysis techniques are also part of the risk analysis and evaluation steps to identify incidents' causes and measure their severity and frequency (Supply Chain Risk Leadership Council [SCRLC], 2011). Moreover, an incident's probability of occurrence is the product of the probability of the hazard's occurrence and the probability of the relevant object being exposed to the hazard; without the latter, the incident is a near-miss, while without the former, the incident is an at-risk behavior (Aven, 2016).

2.2.2. Risk assessment techniques/methods

For both quantitative and qualitative approaches, a wide range of techniques exist. Each technique has its characteristics, advantages, disadvantages, and fields of application.

Qualitative or semi-quantitative techniques, such as hazard matrices, risk graphs, risk matrices, and monographs, are often used for risk screening, whereas sophisticated quantitative techniques, such as actuarial and hybrid risk assessment models, are used to assess complex risks (Berg, 2010). Custom approaches, such as integrated risk calculation and cost-benefit analysis nomograms, analyze the risks of complex projects (Cagno et al., 2007).

Identifying the sources of risk is the most critical stage of the risk assessment process. Proactive risk management targets the sources of risk, as the better the understanding of risk sources, the better the outcome of the risk assessment and the more meaningful and effective the risk management is (Berg, 2010). All information in the risk identification stage flows to the subsequent risk analysis and evaluation stages, where risk analysis supports the evaluation of the nature and distribution of risk and the development of appropriate risk management strategies. Although both qualitative and quantitative techniques analyze and evaluate risks, Monte Carlo simulation could refine the uncertainty of estimating frequency and severity, and enhance the accuracy of quantitative estimates (Australian Government, 2016).

As risks are connected, so do the techniques used in the process of risk assessment. Some techniques are suitable for both risk identification and risk analysis/evaluation, whereas others are specifically for either identification or analysis/evaluation purposes. For example, the layer of protection analysis (LOPA) uses the risk identification outcome of hazard and operability (HAZOP) to conduct further risk analysis and evaluation. Some techniques are used to aid other techniques regarding risk identification, analysis, and/or evaluation. For example, a root cause analysis dives deeper into finding the roots of a low-probability-high-consequence incident, which supplements the results of other risk assessment techniques and enables proactive risk assessment.

In practice, these risk assessment techniques are not necessarily standalone tools used to assess risks but rather a part of another risk assessment or management tool or work in conjunction with the other tools in the process of risk assessment and management. Future research should consider the specific uses of these techniques, tools, and processes to understand and compare their features. For the summary of the risk assessment techniques and their key categories, characteristics, and use cases, see the tables in the research methodology section.

Two main challenges facing risk assessment are variation across time and connected risks. Wassénius and Crona (2022) believe that traditional risk assessment methodologies and techniques are expected to adapt to the increasingly complex and intertwined world by addressing the issue of nonlinear dynamics and nonstandard variation across time and identifying the systemic risks across risk categories. In the case of assessing sustainability risk, the selection of a time reference point or interval is central to overcoming the challenge of variation across time. All risk assessments should incorporate known or feasibly anticipated distal risks into proximate risk assessments to map and capture the causal pathways of interconnected risks. Overcoming these two challenges requires the risk assessment to be a continuous and adaptive process and conduct the periodical reassessment of risk because uncertainty (unknown unknowns) is expected to become risk (known unknowns) when risk assessors' knowledge base grows over time. Risk assessment is expected to continue to be a great and necessary tool to deal with the certain uncertainty of a complex future, namely the time dynamics that cause uncertainty.

As risk assessment methodologies and techniques continue to evolve, the knowledge base of risk assessors and organizations expands. The big database of risk assessment knowledge tracks the transition from uncertainty to risk, which enables the proactive approach to risk management by focusing on uncertainty, the root of risk; section four of the study develops the conceptual framework of a risk assessment knowledge management system that addresses this aspect. The following supplements the use cases of risk assessment techniques by identifying their selection criteria.

2.2.3. The selection criteria of risk assessment tools

Appropriate, accurate methodologies and techniques could reduce the uncertainty in risk assessment outcomes. The choice between quantitative and qualitative techniques depends on large, quality datasets necessary to identify hazards and the level of analysis and evaluation essential to make a confident decision. Mining, manufacturing, power utility, and construction industries demonstrate good practices in selecting risk assessment tools. The selection criteria of risk assessment techniques should fit an enterprise's risk profile and incorporate business unit-specific factors.

The following are the key factors of consideration in selecting risk assessment techniques or methodologies (Mullai, 2006), whereas organizations could add more criteria by incorporating industry-specific factors:

- purpose, complexity, and size of risk analysis;
- legal requirement;
- type of results or information needed;
- data, resources, and time available;
- type of activity or system;
- concerning issues that require sophisticated techniques.

Australian mining companies select risk assessment tools based on business phases and risk consequences. Assessment tools are differentiated by qualitative and quantitative tools or grouped according to the different stages of the risk assessment process. Australian Government (2016) advises that complex techniques generally deliver more accurate results than simple risk assessment tools, however, they involve more cost, time, effort, and specialist expertise regarding risk analysis and evaluation. A combination of risk assessment techniques may be most efficient but they are subject to regular review and continual improvement. Enterprises should consider the following aspects when choosing a risk analysis technique:

- Qualitative risk analysis techniques are simple and useful for sorting risk and determining the level of risk in an organization. However, qualitative techniques are less likely to withstand scrutiny when scenarios become more complex.
- Semi-quantitative risk analysis techniques are easy to use but provide more insight and uniformity than qualitative techniques in terms of risk nature and control.
- Quantitative risk analysis techniques are suitable for making complex decisions for business, environmental, and social issues. However, quantitative methods are less effective for evaluating environmental impact when there is a diverse range of environmental and social issues, as people do not usually place a monetary value on intangible and emotive events. The effectiveness of quantitative risk assessment techniques depends on data availability, specialist expertise, and the capacity and commitment of the organization to manage the risk assessment process.
- The complexity of mathematical models used in fault tree techniques results from the interrelationship between factors and controls. For example, some failures likely occur if some control measures stop working because of common causal factors, such as age, corrosion, design faults, and fire.

The electrical utility industry uses many different risk analysis methods, which is ideal depending on the type of problem in the power distribution system (Nordgård et al., 2009).

The construction industry selects risk assessment techniques according to the nature of the project, organizational policy, project management strategy, the risk attitude of the project team, and available resources (Banaitiene & Banaitis, 2012).

The Department of Internal Affairs New Zealand (2018) uses an activity-based, qualitative risk assessment method to analyze the risk of money laundering by attributing the following aspects with low- or high-risk characteristics:

- the nature, size, and complexity of the business;
- types of customers;
- products and services;
- countries;
- institutions;
- methods for delivering financial products or services to customers.

In the space of criminal justice and forensic psychiatry violence risk assessment, Fazel and Wolf (2018) propose a 10-question guide that researchers, clinicians, and other professionals could use to select the appropriate risk assessment tool.

Decision analysis tools, such as cost-benefit analysis, cost-effectiveness analysis, and multi-attribute analysis, supplement risk assessment. However, these analysis criteria do not adequately reflect uncertainty (Aven & Abrahamsen, 2007; Aven, 2016), hence various risk assessment techniques are an essential part of the decision analysis work, which support the decision-making in selecting the most appropriate risk control measure and determining the acceptable level of residual risk (Pasman et al., 2022).

Alrazig and Ali (2020) highlight experience level as a critical factor that affects decision-making. For example, the best tool may not be apparent to an inexperienced risk assessor, however, as the risk assessor gains more experience or applied knowledge in various methodologies and techniques, such as understanding the advantages and disadvantages of each risk assessment technique, the task of selecting appropriate risk assessment tools become easy and even instinctive.

Regarding the decision-making approach used to improve risk management and process safety, Pasman et al. (2022) propose a list of decision-making methods, such as the Toulmin model of argumentation, multi-criteria decision-making, and the analytic hierarchical process, and determine the optimal tool under uncertainty. Despite being used for risk control purposes, this approach applies to the decision-making process of selecting risk assessment techniques and implementing them in complex situations.

2.3. Risk assessment and knowledge management

Flage and Aven (2015) found that when background knowledge is weak, some emerging risks indicate that a new type of event could occur in the future and potentially have severe consequences on something that humans value. The weak background knowledge makes the specification of scenarios difficult. Further development in risk assessment is expected to address the challenges associated with the issues of knowledge dimension and time dynamics.

Regarding the relationship between knowledge management and risk assessment, Aven and Zio (2018) declare that risk assessment and management are fundamentally based on knowledge and information, however, the procedure of quality assurance on knowledge remains both an open issue and a research challenge. The study confirms the necessity of deploying software technologies, such as natural language processing, content analytics, and formal methods, to assist practitioners with better retrieving risk knowledge and information stored in document databases. Despite some research on knowledge management systems, frameworks, and methods to address uncertainty issues, such as the lack of information and the uncertainty in knowledge acquisition and accuracy, there is no study on the development of a risk assessment knowledge management system to minimize uncertainty in the process of risk assessment.

Through an extensive literature review, the research identifies the importance of operational and strategic risk management. Despite some innovation in the knowledge dimension and time dynamics, the research and development gaps remain for addressing the constant issue of uncertainty in risk assessment, especially for complex systems, because of emerging risks, such as the COVID-19 pandemic, a global systematic risk that has the severe impact on business operations and risk management strategies.

3. RESEARCH METHODOLOGY

The study adopts a qualitative analysis approach to answer research questions and deploys the method of conceptual frameworks to fill research gaps. Literature reviews uncover the research gaps that uncertainty remains an area of further research and development while knowledge is a critical entry point for minimizing uncertainty. Time dynamics is the third factor in play that affects uncertainty.

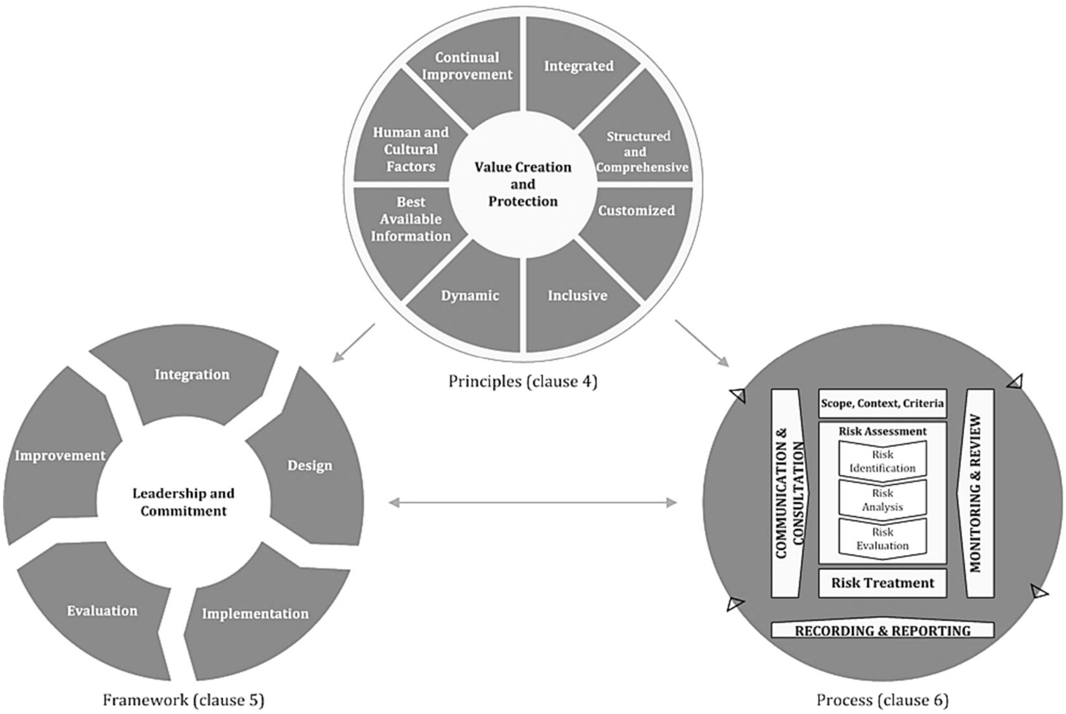
The study aims to address unresolved risk assessment issues driven by three factors, namely uncertainty, knowledge dimension, and time dynamics. The initial findings of the literature review lead to two research questions, previously mentioned in Section 1.

3.1. Research approach and design

Literature reviews focus on studies related to uncertainty, knowledge dimension, and time dynamics by exploring the evolvement, categories, characteristics, use cases, and selection criteria of risk assessment methodologies and techniques; these studies form the knowledge base regarding the uncertainty and time dynamics issues in the process of risk assessment. The analysis of these key findings leads to the appropriate research approaches used to develop the conceptual framework of a risk assessment knowledge management system; it is an effective solution to tackle the three factors that affect risk assessment.

As risk management and assessment issues could be addressed from either a technical or managerial perspective, the risk assessment knowledge management system framework is expected to be an effective, managerial solution to minimize uncertainty in the process of risk assessment by focusing on the major causes of uncertainty, namely the knowledge dimension and time dynamics. The approach for developing the knowledge management system framework is to focus on the pivotal cause of uncertainty, namely the knowledge dimension, and the root of risk, namely uncertainty; this proactive and preventative risk management approach efficiently and sustainably minimizes risks by addressing their critical and root causes. Moreover, the knowledge management system framework also incorporates existing effective solutions, such as combining qualitative judgment with quantitative models, timely risk assessment and re-assessment, and preventative risk control measures.

Figure 1. The ISO 31000 principles, framework, and process



Source: International Organization for Standardization (ISO, 2018a).

As knowledge is a broad term, the study focuses on the fundamental knowledge of risk assessment methodologies and techniques, namely the categories, characteristics, use cases, and selection criteria; both the methodologies and techniques correspond to the main steps of the risk assessment process, namely risk/hazard identification, risk analysis, and risk evaluation, according to the ISO 31000 standards, as illustrated in the process component of Figure 1. This approach addresses the uncertainty in understanding, choosing, and implementing the risk assessment tools in practice by following a structured, standard process. Alternatively, the fundamental knowledge could incorporate more aspects or replace those mentioned above depending on the aim of the study and associated research questions.

The literature review leads to the comparison matrices of primary risk assessment techniques, as illustrated in Tables 1 and 2, which highlight their categories, characteristics, and use cases.

Table 1. The comparison matrix of risk assessment techniques at the stage of risk/hazard identification

Risk assessment stages	***Techniques or methodologies***	***Nature of techniques***			***Typical use cases***
		Qualitative	***Semi-quantitative***	***Quantitative***	
Risk/hazard identification	Risk register	x	x	x	General
	Risk survey	x	x	x	General
	Research and publication	x	x	x	General
	Consultation with staff	x			General
	Risk wheel	x	x		Environment
	Brainstorming	x			Ideation
	Data analytics and econometrics			x	Data relationship modeling
	Industry and legislative requirements	x	x	x	General
	Environmental monitoring and testing	x	x	x	Environment
	Contribution of human factors	x		x	Behavioral safety, ergonomics, healthcare
	Coarse risk analysis	x		x	General
	Preliminary hazard analysis (PHA)		x	x	System safety, environment
	Haddon matrix	x			Health, safety
	Checklist	x			General
	Hazard and operability (HAZOP)	x			Process safety, chemical, mining, power utility, information technology (IT)
	Failure mode and effects analysis (FMEA)	x	x		Process safety, healthcare
	Hazard identification (HAZID)	x			Process and system safety
	Audit	x		x	Compliance
	Structured what-IF technique (SWIFT) (combines checklists and brainstorming)	x			Chemical process
	Walk-through	x			Compliance
	Strength weakness opportunity and threat (SWOT)	x			Strategic planning
	Expert judgement	x			Safety, system quality, and reliability, general

Source: American Bureau of Shipping (2000), French et al. (2017), Bocage et al. (2020), Selitski (2022), Institute for Healthcare Improvement (2017), Rae and Alexander (2017), and Yan and Xu (2019).

Table 1 lists 22 primary techniques used to identify risks or hazards alongside the type of approach and use cases. Qualitative approaches are prominent at the risk or hazard identification stage.

Table 2 includes 74 primary risk analysis and evaluation techniques; they are comprehensive methods that consist of more than a single parameter, namely probability, consequence, exposure, and/or vulnerability. Compared to the risk or hazard identification stage, the percentage of quantitative approaches increases from 45.9% to 60.8% at the risk analysis and evaluation stage.

Along with system engineering standards, the above-mentioned approaches are used to design the conceptual framework of the risk assessment knowledge management system. As shown in Tables 1 and 2, the fundamental knowledge of risk assessment methodologies and techniques demonstrates what form of data or information could be stored and retrieved from the risk assessment knowledge management system.

Table 2. The comparison matrix of risk assessment techniques at the stage of risk analysis and evaluation (Part 1)

Risk assessment stages	*Techniques or methodologies*	*Nature of techniques*			*Typical use cases*
		Qualitative	*Semi-quantitative*	*Quantitative*	
Risk analysis and evaluation	Subjective prioritization	x			General, IT
	Risk register	x	x	x	General
	Risk categorization matrices (a form of scenario analysis)	x	x		Safety, health, oil and gas
	Risk rating matrix with logarithmic scale		x		Safety, health, oil and gas
	Risk appetite matrix	x			Finance, operation
	Risk impact and likelihood matrices	x	x	x	Safety, health, oil and gas
	Risk nomogram		x		Health
	Integrated risk calculation and cost-benefit analysis nomogram		x		Risk assessment dashboards
	Harmonized threat/hazard and risk assessment		x		Safety, IT
	Risk heat map/Isopleth	x			Safety, IT, environment, health
	Risk assessment interviews (a qualitative scenario analysis)	x	x		Safety, psychological risk assessment
	Bowtie analysis		x		General, safety, health, environment
	Advanced bow-tie with control erosion factors and assurance		x		General, safety, health, environment
	Failure modes, effects, and criticality analysis (FMECA) or FMEA	x	x		Process, system and equipment safety, IT, healthcare
	Business impact analysis	x		x	Business process and function disruption
	NIST SP 800-30	x	x		IT
	CCTA risk analysis and management method (CRAMM)	x	x		IT
	Scorecards	x	x		Finance, environment, social and governance, supply chain, IT
	Business process mapping	x	x		Process analysis, training, process improvement, and management
	Comparative analysis	x			General
	Strategic map and risk event card	x	x		General, automotive manufacturing
	Value at risk (VaR) (a form of quantitative scenario analysis)			x	Finance, investment management, banks and insurance
	Peaks-over-threshold (POT) method			x	Finance, environment, operation
	Fuzzy logic, Bayesian belief networks, neuron networks, bootstrapping			x	Prediction/estimation, environment, safety
	Loss distribution approach			x	Operation
	Relative ranking/Risk indexing		x		Quality, safety
	Business process analysis	x			Business process management, hospitals
	Scenario analysis	x		x	General, operation, finance, environment
	Sensitivity analysis	x		x	Finance, project management, simulation modeling, insurance
	Key risk indicators		x	x	IT, operation
	MIL-STD-882 (matrix-based technique)	x			IT, military

Table 2. The comparison matrix of risk assessment techniques at the stage of risk analysis and evaluation (Part 2)

Risk assessment stages	*Techniques or methodologies*	*Nature of techniques*			*Typical use cases*
		Qualitative	*Semi-quantitative*	*Quantitative*	
Risk analysis and evaluation	Consequence table	x	x		General, safety, health, environment, operation
	Tornado diagram			x	Sensitivity analysis, project management
	Decision tree analysis			x	Project management, finance, environment, health, safety
	Modeling and simulation			x	Process safety, construction safety, IT, healthcare
	Crime risk assessment mechanism			x	Law enforcement, finance
	Accident prediction model (APM)			x	Road safety
	Surrogate safety assessment model (SSAM)			x	Road safety
	Human health risk assessment			x	Health, ergonomics
	Environmental risk assessment (ERA)	x		x	Environment
	Natural disaster risk assessment	x	x	x	Environment, flood, wildfire
	Disaster risk assessment	x	x	x	Health, IT, conflict, war, safety
	Terrorist attack risk assessment	x	x	x	Terrorism, safety, security
	Force field analysis	x			Change management, environment
	Pareto analysis/A-B-C analysis			x	Finance, inventory management, operations management, general
	Microsoft corporate security group risk management framework			x	IT
	Preliminary risk analysis	x		x	Health
	Root causes analysis (RCA)	x		x	General, safety, health, IT
	Human reliability analysis (HRA) (a form of fault tree and event tree analysis)	x		x	Safety, transportation, power utility, petroleum
	Structured what-IF technique (SWIFT)	x			Chemical process, healthcare
	Events and causal factor charts	x			Safety, health
	Hazard analysis and critical control points (HACCP)	x		x	Safety, food, drugs, quality
	Critical control point (CCP)	x		x	Safety, mining, food
	Environmental risk and impact assessment	x		x	Environment
	Change analysis (ChA)	x		x	General
	Bayesian analysis	x		x	Environment, IT, operation, food
	Resilience engineering	x		x	Safety, construction
	Functional resonance analysis method (FRAM) and System-theoretic accident model and processes (STAMP)	x			Safety, operation, manufacturing, cruise and ferry
	Reliability centered maintenance	x		x	Safety, security, maritime
	Layer of protection analysis (LOPA)		x		Chemical safety, safety instrumented system
	Sneak circuit analysis	x			Electrical safety, electro-mechanical safety, system safety, IT
	Markov analysis	x		x	System behavior, power utility

Table 2. The comparison matrix of risk assessment techniques at the stage of risk analysis and evaluation (Part 3)

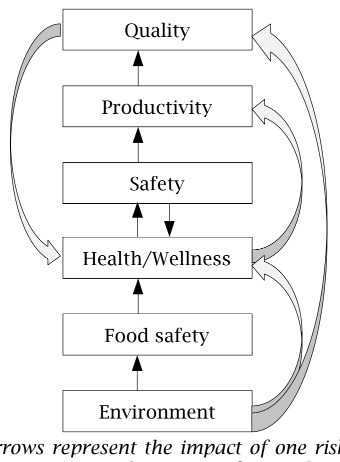
Risk assessment stages	*Techniques or methodologies*	*Nature of techniques*			*Typical use cases*
		Qualitative	*Semi-quantitative*	*Quantitative*	
Risk analysis and evaluation	Multi-criteria decision analysis (MCDA)	x		x	Environment, food, pharmaceuticals
	The triplet (C', Q, K)	x			Safety
	Electrical system simulation			x	Electrical safety
	Benchmarking methods	x		x	General, safety, IT
	Operationally critical threat, asset, and vulnerability evaluation (OCTAVE)	x			Operation security, IT
	Factor analysis of information risk (FAIR)			x	IT, operation
	Threat assessment and risk analysis (TARA)	x		x	IT
	ISACA's COBIT 5	x		x	IT
	F-N curve			x	Societal risk, safety
	Risk density curve			x	Environment
	Risk profile	x		x	General, finance
	Cost analysis (e.g., cost-benefit, cost-effectiveness)			x	General, environment

Source: American Bureau of Shipping (2000), Willey (2014), Morita (2014), Risk Engineering (2022), Ranasinghe et al. (2020), Aven (2016), Belhaj and Tkiouat (2013), Mestchian et al. (2005), SCRLC (2011), Australian Government (2016), Kaplan and Mikes (2012), United States EPA (n.d.-b); Sutherland et al. (2021), Donovan (2022), Acar et al. (2021), Subagyo et al. (2020), Rail Safety Standards Board (2021), Kalathil et al. (2020), U.S. Department of Homeland Security (2023), Ferris (2021), Marhaditha and Pangeran (2022), Şimşek (2024), Caburao (2024), Astarita et al. (2019), Qazi and Simsekler (2021), Hlalele (2019), Birch (2021), Priya and Chaudhary (2021), Kaikkonen et al. (2021), Fung et al. (2020), Naeini and Nadeau (2021), Parihar and Bhar (2019), Ali et al. (2022), Williams (2019), Shingler et al. (2017), and Pasman et al. (2022).

3.2. Alternative methods of conducting the study

Alternative research methods are conducting primary interviews to obtain the opinions of subject matter experts in the space of risk assessment. This qualitative approach gathers experts' views on research gaps and potential solutions to unresolved issues in risk assessment. One way of approaching the uncertainty issue could be from the interrelationships among risks, such as OHSEQ, as illustrated in Figure 2. For example, environmental risks have an impact on food safety and in turn, affect people's health or wellness. In the same vein, workers' health conditions likely lead to unsafe behavior and subsequently productivity issues, which eventually affect the quality of work, products, and service.

Figure 2. The model of key transmission effects among the OHSEQ risks



Note: Black arrows represent the impact of one risk on the next risk; grey arrows represent the impact of one risk on another risk that is not next to each other.

Statistical and mathematical models could also be used to assess the levels of correlation and significance of knowledge dimension, time dynamics, and the other potential explanatory variables of uncertainty. However, these quantitative models require a substantial amount of time series and cross-sectional data to yield more robust results than the qualitative approach, which may not be available immediately.

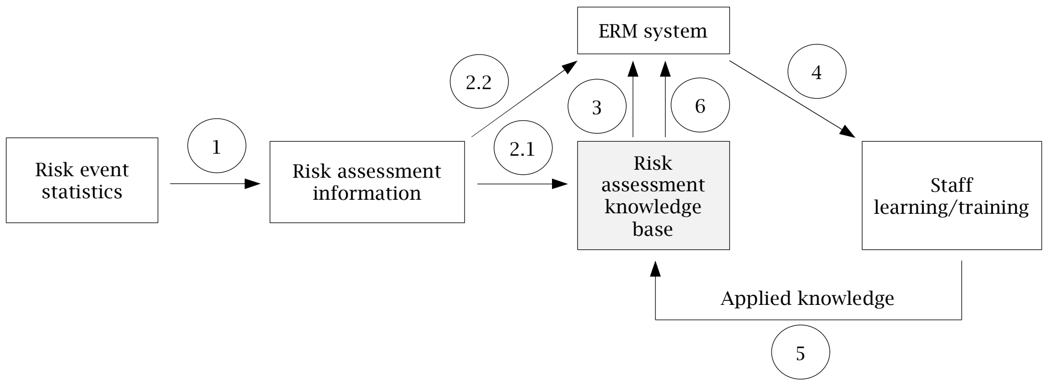
4. RESULTS

Based on the findings and insights of previous sections, this section develops a knowledge management system framework, which addresses the constant challenge faced by risk assessment and management practitioners through continually enhancing their knowledge base of risk assessment expertise. Some typical examples of this knowledge are the practical know-how (namely, tacit knowledge) of the exposure factors to risk events, the step of the risk assessment process at which these tools are most effective, and how risk assessment tools are applied in certain use cases. The conceptual framework is based on the approaches outlined in the methodology section of the study and aims to minimize uncertainty in the process of risk assessment by focusing on the knowledge dimension as a pivotal factor.

Compared to a manual process and addressing the factors of knowledge dimension and time dynamics separately, the risk assessment knowledge management system framework focuses on the knowledge dimension, the pivotal cause of uncertainty, which is an efficient and sustainable strategy to minimize uncertainty in risk assessment. The following unpacks the risk assessment knowledge management system framework by explaining the components and how they work together as a system.

The risk assessment knowledge management system facilitates knowledge sharing among users and reduces the knowledge silos across an organization; the knowledge base forms a big data repository, which is the core of the management system and supports the implementation of quantitative risk assessment methodologies and techniques. Risk assessors and the other stakeholders of risk assessment could continually improve their knowledge and reassess risks over time, which minimizes uncertainty in risk assessment and associated decision-making processes. The conceptual framework is based on the flow model of information systems and technology, which indicates the transformation from statistical data, information, and knowledge to applied knowledge and explains the ever-expanding knowledge base, as indicated in the grey square of Figure 3. The ERM system allows the risk assessment knowledge base to have an enterprise-wide view of risk and facilitates the sharing of risk assessment knowledge. The following explains step-by-step how the conceptual framework functions.

Figure 3. The conceptual framework of the risk assessment knowledge management system



Note: The number in the circle indicates the order of workflow steps; the arrow indicates the direction of the workflow.

As illustrated in Figure 3, risk event statistics are the data source of the risk assessment knowledge management system and flow through the process of risk assessment; the consolidated event data and risk assessment results flow to both the ERM system and the risk assessment knowledge base at the same time, as shown in steps 2.2 and 2.1, respectively. The risk assessment knowledge base plays the pivotal role of collecting and organizing risk assessment information and associated practical experience, which feeds the knowledge into the ERM system and works in conjunction with the ERM system to provide a collaborative learning platform to the staff of the organization, as indicated in steps 3 and 4, respectively. By leveraging the ERM software system's collaborative functions, staff could learn by training, self-reading, and knowledge/experience sharing, among other learning activities; employees could potentially develop innovative solutions in the process of learning, which adds the applied knowledge to the risk assessment knowledge base and in turn to the ERM system, as indicated in steps 5 and 6, respectively.

Eventually, the risk assessment knowledge base shows the spiral growth of applied knowledge because of staff's continual learning and contribution; this risk assessment knowledge management system keeps staff's know-how up to date and reduces uncertainty in risk assessment due to the lack of knowledge in, for example, exposure factors and risk assessment tools; which technique is qualitative, quantitative or semi-quantitative, often used at which stage of the risk assessment process, and effective in which use cases; what are the factors to take into account when selecting the appropriate techniques and what are the implementation good practices, as discussed in the literature review section of the study.

5. DISCUSSION

As proposed in Section 4, the risk assessment knowledge management system framework demonstrates an innovative risk assessment strategy and fills the research and development gap by addressing the two major causes of uncertainty, namely knowledge dimension and time dynamics, in which knowledge dimension plays a pivotal role in the causes of uncertainty. Through this learning platform, staff could keep abreast of emerging risks and global trends by continually gaining applied knowledge, which minimizes uncertainty in both decision-making and risk assessment processes. The spiral growth of the applied knowledge base is a sustainable way of minimizing uncertainty and in turn risk. As revealed in the research by Evrin (2021), risk assessment frameworks aim to minimize enterprise-wide risks by deploying the appropriate control measures based on risk assessment results; the risk assessment knowledge management system lays the foundation for enabling risk assessment frameworks to minimize risks.

For the risk assessment knowledge management system framework and associated software product to be functional and effective, it relies on the documentation of the risk assessment information, knowledge, and applied knowledge, such as risk assessment failure data and incident patterns; both the applied knowledge and the quality of documentation reflect the effectiveness and timeliness of dynamically solving the real problems of uncertainty in the process of risk assessment.

6. CONCLUSION

Both risk management and assessment are not new terms and they have evolved for decades. Today, various methodologies and techniques, such as

FMEA and bow-tie analysis, apply across industries, such as mining, manufacturing, and construction.

As enterprise risk branches into many different categories based on the consequences of incidents, the study focuses on operational, strategic, and hazard risks; many methodologies and techniques could assess and control these risks, such as the OHSEQ risks. With the evolution of risk assessment methodologies and techniques, the ISO 31000 risk management principles and guidelines transform into a less prescriptive thought process and allow organizations to develop their frameworks, processes, and models that fit their risk characteristics (ISO, 2018b). In line with this trend, the combination of qualitative, semi-quantitative, and quantitative risk assessment approaches is expected to meet the specific requirements of an organization and its work activities. In the space of cybersecurity, enterprises are expected to adopt industry standard frameworks, such as the NIST SP 800-30, because the development of organization-specific approaches likely misses critical elements, which might skew the understanding of risk.

Organizations' internal risks, such as occupational health and safety, are more controllable than external risks, such as natural disasters. Quantitative or semi-quantitative methods, such as VaR and Monte Carlo simulation, improve the reliability of risk assessment and are ideal for assessing high-consequence incidents. Although both qualitative and semi-quantitative methods, such as brainstorming and risk matrices, are easy to understand and implement, the assessment outcome is limited by assumptions and opinions.

The majority of both qualitative and semi-quantitative techniques derive from risk matrices, where probability (likelihood or frequency) and consequence (impact or severity) are the two parameters used to analyze and evaluate risks. Some quantitative techniques incorporate exposure and/or vulnerability parameters, which assess more complex and technical risks, such as health and cybersecurity incidents. Moreover, some techniques, such as HAZOP and fault tree analysis, only have one parameter, namely frequency or severity, while other techniques, such as the bow-tie analysis, incorporate parameters suitable for risk identification, analysis, and evaluation. The study focuses on risk analysis and evaluation techniques that consist of more than one parameter.

Quantitative techniques based on mathematics or simulation models are most effective in assessing systematic risks that usually have severe consequences, such as natural disasters and terrorist attacks. However, the high level of uncertainty of these rare incidents results in less reliable risk assessment outcomes. The literature review unveils existing practices, such as the combination of qualitative, semi-quantitative, and quantitative approaches, that have not eliminated the issues of uncertainty, knowledge dimension, and time dynamics, especially for risk events that involve a diverse range of environmental, social, and communicational issues. Substantial research and development are necessary to generate adequate modelling and analytical methods to deal with different and complex systems, such as power generation, transmission, and distribution infrastructures.

As an innovative research and development solution to address the unresolved issues related to uncertainty, knowledge dimension, and time dynamics, the study proposes the conceptual framework of a risk assessment knowledge management system that focuses on the root of these issues, namely knowledge dimension, which is based on industry best practices, risk management approaches, and system engineering standards. The strategic rationale behind the framework is that the spiral growth of applied knowledge in the organization enhances the quality of decision-making and continually improves the outcome of risk assessment through this big data software platform; risk assessors and the other stakeholders of the risk assessment process keep abreast of emerging risks and global trends through continual learning. The risk assessment knowledge management system provides the knowledge base, knowledge sharing, and training facilities, which over time minimizes the issue of uncertainty and time dynamics caused by the lack of timely, effective applied knowledge. Hence, the conceptual framework is efficient and sustainable by addressing the root and pivotal causes of uncertainty and in turn minimizing risk through the continued improvement in risk assessment knowledge base and staff training. This development work adds value by filling research gaps and advances toward reducing uncertainty in the process of risk assessment, a critical yet challenging issue.

As the research aims to develop the conceptual framework of the risk assessment knowledge management system, the framework could guide the development of a software product and solve various risk assessment and management issues across industries and countries, which is expected to be part of future research and development. As the research primarily focuses on the interrelationship among three factors, namely uncertainty, knowledge dimension, and time dynamics, the key research findings and associated conceptual framework are limited by the depth of the factor analysis, in other words, the elements that underline each factor; these limitations could impact the precision of the conceptual framework regarding the minimization of uncertainty in the process of risk assessment. Further research is expected to provide empirical evidence and reveal the areas for improvement in the conceptual framework and associated software architecture, such as the specific workflow steps that address the uncertainty and time dynamics issues, respectively.

REFERENCES

Acar, H. C., Can, G., Karaali, R., Börekçi, Ş., Balkan, İ. İ., Gemicioğlu, B., Konukoğlu, D., Erginöz, E., Erdoğan, M. S., & Tabak, F. (2021). An easy-to-use nomogram for predicting in-hospital mortality risk in COVID-19: A retrospective cohort study in a university hospital. *BMC Infectious Diseases, 21*, Article 148. https://doi.org/10.1186/s12879-021-05845-x

Akhavan, P., Shahabipour, A., & Hosnavi, R. (2018). A model for assessment of uncertainty in tacit knowledge acquisition. *Journal of Knowledge Management, 22*(2), 413–431. https://doi.org/10.1108/JKM-06-2017-0242

Ali, B. M., Andersson, M. G., van den Borne, B. H. P., Focker, M., & van der Fels-Klerx, H. J. (2022). Multi-criteria decision analysis in food safety risk management: The case of dioxins in Baltic fish. *Foods, 11*(7), Article 1059. https://doi.org/10.3390/foods11071059

Alrazig, M. A., & Ali, D. K. M. (2020). Approaches for risk assessment method selection criteria. *American Scientific Research Journal for Engineering, Technology, and Sciences, 74*(2), 242–253. Retrieved from https://asrjetsjournal.org/index.php/American_Scientific_Journal/article/view/6441

American Bureau of Shipping. (2000). *Guidance notes on risk assessment: Applications for the marine and offshore oil and gas industries.*

Astarita, V., Festa, D. C., Giofrè, V. P., & Guido, G. (2019). Surrogate safety measures from traffic simulation models: A comparison of different models for intersection safety evaluation. *Transportation Research Procedia, 37*, 219–226. https://doi.org/10.1016/j.trpro.2018.12.186

Australian Government. (2016). *Risk management: Leading practice sustainable development program for the mining industry.* Commonwealth of Australia. https://www.industry.gov.au/sites/default/files/2019-04/lpsdp-risk-management-handbook-english.pdf

Aven, T. (2016). Risk assessment and risk management: Review of recent advances on their foundation. *European Journal of Operational Research, 253*(1), 1–13. https://doi.org/10.1016/j.ejor.2015.12.023

Aven, T., & Abrahamsen, E. B. (2007). On the use of cost-benefit analysis in ALARP processes. *International Journal of Performability Engineering, 3*(3), 345–353. http://www.ijpe-online.com/EN/Y2007/V3/I3/345

Aven, T., & Flage, R. (2018). Risk assessment with broad uncertainty and knowledge characterisation. In T. Aven & E. Zio (Eds.), *Knowledge in risk assessment and management* (pp. 1–26). John Wiley & Sons Ltd. https://doi.org/10.1002/9781119317906.ch1

Aven, T., & Zio, E. (2018). *Knowledge in risk assessment and management.* John Wiley & Sons Ltd. https://doi.org/10.1002/9781119317906

Backhouse, K., & Wickham, M. (2020). Corporate governance, boards of directors and corporate social responsibility: The Australian context. *Corporate Ownership & Control, 17*(4), 60–71. https://doi.org/10.22495/cocv17i4art5

Banaitiene, N., & Banaitis, A. (2012). Risk management in construction projects. In N. Banaitiene (Ed.), *Risk management — Current issues and challenges.* IntechOpen. https://doi.org/10.5772/51460

Bao, C., Li, J., & Wu, D. (Eds.). (2022). Three-dimensional risk matrix: Theoretical basis and construction. In *Risk matrix. Rating scheme design and risk aggregation* (pp. 149–169). Springer, Singapore. https://doi.org/10.1007/978-981-19-1480-5_8

Beers, B. (2022, October 31). *How do modern companies assess business risk?* Investopedia. http://www.investopedia.com/ask/answers/061015/how-do-modern-companies-assess-business-risk.asp

Belhaj, R., & Tkiouat, M. (2013). A Markov model for human resources supply forecast dividing the HR system into subgroups. *Journal of Service Science and Management, 6*(3), 211–217. https://doi.org/10.4236/jssm.2013.63023

Berg, H.-P. (2010). Risk management: Procedures, methods and experiences. *Reliability: Theory & Applications, 1*(2010, June), 79–95. https://sswm.info/sites/default/files/reference_attachments/BERG%202010%20Risk%20Management%20Procedures,%20Methods%20and%20Experiences.pdf

Birch, D. S. (2021). *Development of a human factors hazard model for use in system safety analysis* [Doctoral dissertation, Colorado State University]. Colorado State University. https://www.proquest.com/openview/d440ba889ded910f1416347e95b58e81/1?pq-origsite=gscholar&cbl=18750&diss=y

Bocage, C., Mashalla, Y., Motshome, P., Fane, O., Masilo-Nkhoma, L., Mathiba, O., Mautle, E., Kuiperij, B., Mmusi, T., Holmes, J. H., Tam, V., Barg, F. K., & Wiebe, D. J. (2020). Applying the Haddon matrix conceptual model to guide motor vehicle crash injury research and prevention in Botswana. *African Journal of Emergency Medicine, 10*(Supplement 1), S38–S43. https://doi.org/10.1016/j.afjem.2020.04.006

Bratianu, C., & Bolisani, E. (2015). Knowledge strategy: An integrated approach for managing uncertainty. In A. Garlatti & M. Massaro (Eds.), *Proceedings of the 16th Conference on Knowledge Management* (pp. 169-177). Reading: Academic Conferences and Publishing International. https://shorturl.at/fq6nl

Caburao, E. A. (2024, June 13). *A comprehensive guide to process analysis.* SafetyCulture. https://safetyculture.com/topics/process-analysis/

Cagno, E., Caron, F., & Mancini, M. (2007). A multi-dimensional analysis of major risks in complex projects. *Risk Management, 9*(1), 1–18. https://doi.org/10.1057/palgrave.rm.8250014

Cioca, L.-I., Băbut, G.-B., & Moraru, R.-I. (2010). Occupational risk assessment and management: Challenges and guidelines for the Romanian organization's practice. *WSEAS Transactions on Advances in Engineering Education, 4*(7), 119–128. http://www.wseas.us/e-library/transactions/education/2010/89-782.pdf

Donovan, L. (2022, November 2). *What is risk appetite and how do you implement it?* Risk Leadership Network. https://www.riskleadershipnetwork.com/insights/what-is-risk-appetite-and-how-do-you-implement-it

Eceiza, J., Kristensen, I., Krivin, D., Samandari, H., & White, O. (2020, April 13). *The future of operational-risk management in financial services.* McKinsey & Company. https://www.mckinsey.com/capabilities/risk-and-resilience/our-insights/the-future-of-operational-risk-management-in-financial-services

Evrin, V. (2021). *Risk assessment and analysis methods: Qualitative and quantitative.* ISACA. https://www.isaca.org/resources/isaca-journal/issues/2021/volume-2/risk-assessment-and-analysis-methods

Fazel, S., & Wolf, A. (2018). Selecting a risk assessment tool to use in practice: A 10-point guide. *BMJ Mental Health, 21*(2), 41–43. https://doi.org/10.1136/eb-2017-102861

Ferris, M. (2021). *Cyber risk scorecard.* WhiteHawk. https://www.energy.gov/sites/default/files/2021-06/Terry%20Roberts%20WhiteHawk-A1.pdf

Flage, R., & Aven, T. (2015). Emerging risk — Conceptual definition and a relation to black swan types of events. *Reliability Engineering & System Safety, 144*, 61–67. https://doi.org/10.1016/j.ress.2015.07.008

French, M., Alem, N., Edwards, S. J., Coariti, E. B., Cauthin, H., Hudson-Edwards, K. A., Luychx, K., Quintanilla, J., & Miranda, O. S. (2017). Community exposure and vulnerability to water quality and availability: A case study in the mining-affected Pazña Municipality, Lake Poopó Basin, Bolivian Altiplano. *Environmental Management, 60*(2017), 555–573. https://doi.org/10.1007/s00267-017-0893-5

Fung, I. W. H., Tam, V. W. Y., Chu, J. O. C., & Le, K. N. (2020). A stress-strain model for resilience engineering for construction safety and risk management. *International Journal of Construction Management, 22*(12), 2308–2324. https://doi.org/10.1080/15623599.2020.1783602

Hlalele, B. M. (2019). Application of the force-field technique to drought vulnerability analysis: A phenomenological approach. *Jàmbá: Journal of Disaster Risk Studies, 11*(1), Article 589. https://doi.org/10.4102/jamba.v11i1.589

Hoffmann, S., Whaley, P., & Tsaioun, K. (2022). How evidence-based methodologies can help identify and reduce uncertainty in chemical risk assessment. *ALTEX — Alternatives to Animal Experimentation, 39*(2), 175–182. https://doi.org/10.14573/altex.2201131

Institute for Healthcare Improvement. (2017). *Failure modes and effects analysis (FMEA) tool.* https://www.ihi.org/resources/Pages/Tools/FailureModesandEffectsAnalysisTool.aspx

International Organization for Standardization (ISO). (2018a). *ISO 31000:2018(en) Risk management — Guidelines.* https://www.iso.org/obp/ui#iso:std:iso:31000:ed-2:v1:en

International Organization for Standardization (ISO). (2018b). *Risk management ISO 31000.* https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100426.pdf

Jain, R., Nauck, F., Poppensieker, T., & White, O. (2020, November 17). *Meeting the future: dynamic risk management for uncertain times.* McKinsey & Company. https://www.mckinsey.com/capabilities/risk-and-resilience/our-insights/meeting-the-future-dynamic-risk-management-for-uncertain-times#/

Jones, K., & Jarvis, L. (2020, September 3). Breaking down silos to improve risk assessments in foreign jurisdictions. *Corporate Compliance Insights.* https://www.corporatecomplianceinsights.com/silos-risk-assessments-foreign-jurisdictions/

Kaikkonen, L., Parviainen, T., Rahikainen, M., Uusitalo, L., & Lehikoinen, A. (2021). Bayesian networks in environmental risk assessment: A review. *Integrated Environmental Assessment and Management, 17*(1), 62–78. https://doi.org/10.1002/ieam.4332

Kalathil, M. J., Renjith, V. R., & Augustine, N. R. (2020). Failure mode effect and criticality analysis using Dempster Shafer theory and its comparison with fuzzy failure mode effect and criticality analysis: A case study applied to LNG storage facility. *Process Safety and Environmental Protection, 138*, 337–348. https://doi.org/10.1016/j.psep.2020.03.042

Kaplan, R. S., & Mikes, A. (2012). Managing risks: A new framework. *Harvard Business Review.* https://hbr.org/2012/06/managing-risks-a-new-framework

KPMG. (2019). *Dynamic risk assessment.* https://assets.kpmg.com/content/dam/kpmg/au/pdf/2017/dynamic-risk-assessment-four-dimensional-view.pdf

Mahdi, A. G., Raoof, L. Q., & Ramadhan, H. A. (2020). The role of knowledge management in processing of informational uncertainty of managers. *International Journal of Research in Social Sciences and Humanities, 10*(4), 53–64. https://doi.org/10.37648/ijrssh.v10i04.006

Marhaditha, S., & Pangeran, P. (2022). Supply chain risk management based on ISO 31000:2018 — Balanced scorecard to improve company performance: Case study on UD INTR Yogyakarta. *International Journal of Social Science Research and Review, 5*(11), 307–319. https://ijssrr.com/journal/article/view/705

Martins, Y. S., Sanches da Silva, C. E., Sampaio, P. A. da C. A., & Catalani Gabriel, L. (2021). ISO 9001:2015 and risk-based thinking: scientific research insights. *Total Quality Management & Business Excellence, 33*(11–12), 1326–1343. https://doi.org/10.1080/14783363.2021.1954898

Mestchian, P., Mirzai, B., & Makarov, M. (2005). Operational risk — COSO re-examined. *Journal of Risk Intelligence, 6*(3), 19–22. http://www.risknet.de/fileadmin/eLibrary/OpRisk-COSO-Mestchian-SAS-Risk-Journal-2005.pdf

Moe, S. J., Benestad, R. E., & Landis, W. G. (2022). Robust risk assessments require probabilistic approaches. *Integrated Environmental Assessment and Management, 18*(5), 1133–1134. https://doi.org/10.1002/ieam.4660

Mohammed, A., & Sykes, R. (2012). *Sharpening strategic risk management.* PwC. https://www.pwc.com/gx/en/governance-risk-compliance-consulting-services/resilience/publications/pdfs/issue1/sharpening_strategic_risk_management.pdf

Morita, M. (2014). Flood risk impact factor for comparatively evaluating the main causes that contribute to flood risk in urban drainage areas. *Water, 6*(2), 253–270. https://doi.org/10.3390/w6020253

Mullai, A. (2006). *Risk management system — Risk assessment frameworks and techniques.* DaGoB. https://portal.research.lu.se/en/publications/risk-management-system-risk-assessment-frameworks-and-techniques

Naeini, A. M., & Nadeau, S. (2021). *FRAM and STAMP: New avenue for risk analysis in manufacturing in the era of Industry 4.0* (Paper No. B. 12.7). https://espace2.etsmtl.ca/id/eprint/22345/1/Nadeau-S-2021-22345.pdf

Nagendrakumar, N., Kumarapperuma, C., Malinga, C., Gayanthika, K., Amanda, N., & Perera, A. (2022). Corporate governance and firm integrated performance: A conceptual framework. *Corporate Governance and Sustainability Review, 6*(2), 8–17. https://doi.org/10.22495/cgsrv6i2p1

National Institute of Standards and Technology (NIST). (2012). *Guide for conducting risk assessments information technology* (NIST Special Publication 800-30 Revision 1). https://nvlpubs.nist.gov/nistpubs/Legacy/SP/nistspecialpublication800-30r1.pdf

Nordgård, D. E., Sand, K., & Wangensteen, I. (2009). *Risk assessment methods applied to electricity distribution system asset management.* https://www.sintef.no/globalassets/project/riskdsam/esrel09-risk-assessment.pdf

Parihar, S., & Bhar, C. (2019). Markov analysis as a tool for developing a model for risk management: A case study based on electrical transmission line installation projects. *Optimization: Journal of Research in Management, 11*(1), 22–29. https://www.i-scholar.in/index.php/Optim/article/view/189004

Pasman, H. J., Rogers, W. J., & Behie, S. W. (2022). Selecting a method/tool for risk-based decision making in complex situations. *Journal of Loss Prevention in the Process Industries, 74*, Article 104669. https://doi.org/10.1016/j.jlp.2021.104669

Priya, & Chaudhary, M. (2021). Hazard analysis and critical control points as a quality risk management tool in the pharmaceutical industry: A systematic review. *Journal of Drug Delivery and Therapeutics, 11*(5–S), 167–175. https://doi.org/10.22270/jddt.v11i5-S.5094

Qazi, A., & Simsekler, M. C. E. (2021). Assessment of humanitarian crises and disaster risk exposure using data-driven Bayesian Networks. *International Journal of Disaster Risk Reduction, 52*, Article 101938. https://doi.org/10.1016/j.ijdrr.2020.101938

Rae, A., & Alexander, R. D. (2017). Forecasts or fortune-telling: When are expert judgements of safety risk valid? *Safety Science, 99*(Part B), 156–165. https://doi.org/10.1016/j.ssci.2017.02.018

Rail Safety Standards Board. (2021, August 24). *Bowties in rail — Case studies.* https://www.rssb.co.uk/en/safety-and-health/guidance-and-good-practice/bowties/bowties-in-rail-case-studies

Ranasinghe, U., Jefferies, M., Davis, P., & Pillay, M. (2020). Resilience engineering indicators and safety management: A systematic review. *Safety and Health at Work, 11*(2), 127–135. https://doi.org/10.1016/j.shaw.2020.03.009

Risk Engineering. (2022, July 24). *Farmer's diagram, or F-N curve representing society's degree of catastrophe aversion.* https://risk-engineering.org/concept/Farmer-diagram

Selitski, O. (2022, September 20). *HAZOP vs HAZID — When is one more useful than the other?* ORS Consulting. https://www.ors-consulting.com/hazop-vs-hazid

Shingler, J., Sonnenberg, S. J., & Needs, A. (2017). Risk assessment interviews: exploring the perspectives of psychologists and indeterminate sentenced prisoners in the United Kingdom. *International Journal of Offender Therapy and Comparative Criminology, 62*(10), 3201–3224. https://doi.org/10.1177/0306624X17739211

Şimşek, H. (2024, March 1). What is process mapping & its 7 best practices in 2024? https://research.aimultiple.com/process-mapping/

Subagyo, E., Kholil, K., & Ramli, S. (2020). Risk assessment using bowtie analysis: A case study at gas exploration industry PT XYZ Gresik East Java Indonesia. *Process Safety Progress, 40*(2), Article e12190. https://doi.org/10.1002/prs.12190

Sun, J. (2018). Organizational leadership as a factor of building corporate culture and performance. Corporate *Governance and Organizational Behavior Review, 2*(2), 15–24. https://doi.org/10.22495/cgobr_v2_i2_p2

Sun, J. (2022). The route to corporate social value via health and safety performance, productivity, and management quality. *Corporate Governance and Sustainability Review, 6*(2), 54–68. https://doi.org/10.22495/cgobr_v2_i2_p2

Sun, J., & Van Rooyen, J. H. (2011). A modelling process of short-term interest rate risk management for the South African commercial banking sector. *Corporate Ownership &Control, 9*(1–6), 628–637. https://doi.org/10.22495/cocv9i1c6art6

Supply Chain Risk Leadership Council (SCRLC). (2011). *Supply chain risk management: A compilation of best practices.* http://www.scrlc.com/articles/Supply_Chain_Risk_Management_A_Compilation_of_Best_Practices_final%5B1%5D.pdf

Sutherland, H., Recchia, G., Dryhurst, S., & Freeman, A. L. J. (2022). How people understand risk matrices, and how matrix design can improve their use: Findings from randomized controlled studies. *Risk Analysis, 42*(5), 1023–1041. https://doi.org/10.1111/risa.13822

The Department of Internal Affairs New Zealand. (2018). Risk assessment guideline. https://www.dia.govt.nz/Pubforms.nsf/URL/AMLCFT-Risk-Assessment-Guideline-2018.pdf/$file/AMLCFT-Risk-Assessment-Guideline-2018.pdf

The UK National Cyber Security Centre. (2023, June 23). *Risk management.* https://www.ncsc.gov.uk/collection/risk-management

U.S. Department of Homeland Security. (2023, December 26). *Business impact analysis.* https://www.ready.gov/business-impact-analysis

United States Environmental Protection Agency (EPA). (n.d.-a). *Uncertainty and variability.* https://www.epa.gov/expobox/uncertainty-and-variability

United States Environmental Protection Agency (EPA). (n.d.-b). *Risk assessment guidance.* https://www.epa.gov/risk/risk-assessment-guidance

United States National Research Council Committee on Risk Assessment of Hazardous Air Pollutants. (1994). *Science and judgment in risk assessment.* National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK208260/

Wassénius, E., & Crona, B. I. (2022). Adapting risk assessments for a complex future. *On Earth, 5*(1), 35–43. https://doi.org/10.1016/j.oneear.2021.12.004

Willey, R. J. (2014). Layer of protection analysis. *Procedia Engineering, 84*, 12–22. https://doi.org/10.1016/j.proeng.2014.10.405

Williams, S. (2019). Use of STAMP/STPA to model organizational risk and safety management at cruise and ferry companies. *MATEC Web of Conferences, 273*, Article 02004. https://doi.org/10.1051/matecconf/201927302004

Yan, F., & Xu, K. (2019). Methodology and case study of quantitative preliminary hazard analysis based on cloud model. *Journal of Loss Prevention in the Process Industries, 60*, 116–124. https://doi.org/10.1016/j.jlp.2019.04.013