Understanding project cost contingency estimation: A holistic risk perspective

Abstract

Purpose—Cost contingency is widely employed to address project risks. This systematic literature review aims to develop a framework for understanding risks in project cost contingency estimation.

Methodology—A systematic literature review of 859 abstracts and 67 full articles was conducted using a framework synthesis method.

Finding—The study establishes a six-element risk framework for project cost contingency estimation, encompassing event, consequence, uncertainty, probability, knowledge, and mitigation. Twelve risk dimensions in the project cost contingency estimation are further developed.

Originality/Value—This study contributes to the project management literature by constructing a framework for understanding risks and estimating project cost contingency. This framework provides guidance for enhancing the accuracy of project cost contingency estimation.

Keywords: Project cost contingency; Risk; Systematic literature review; Framework

1 Introduction

Facing great risk in projects, an effective approach is to develop a project cost contingency plan (Curto *et al.*, 2022; Lee *et al.*, 2017). Effective project cost contingency estimation relies on risk assessment (Won *et al*., 2019). Studies have identified three primary approaches to risk assessment in estimating project cost contingency. The first approach takes a process perspective, estimating cost contingency by accumulating the impacts of individual risks. It focuses on specific project risk characteristics, such as risk probability (Jung *et al*., 2016), joint impacts on cost and schedule (Eldosouky *et al*., 2014), and associated uncertainties (Curto *et al*., 2022). The second approach uses an outcome perspective, treating all risks as a whole, such as calculating the overall probability of the project cost overrun (Love *et al*., 2015; Para-González, 2018). The third approach assesses risk sources, using historical data to quantify factors like project size, complexity, and technical difficulty that affect cost contingency (Hammad *et al*., 2016; Sonmez *et al*., 2007).

While these studies emphasize the importance of risk assessment in project cost contingency estimation, there is still a lack of a cohesive framework for understanding risks. As a consequence, the findings were less comparable across the research. For example, Curto *et al*. (2022) argue that three types of uncertainties must be considered in project cost contingency estimation, whereas Eldosouky *et al*. (2014) suggest that fundamental uncertainties, such as estimation errors and productivity fluctuations, should be excluded. Fateminia and Fayek (2023) advocate for including secondary and residual risks, while Islam *et al*. (2021) focus solely on mitigable risks, ignoring secondary risks.

The definition and measurement of risks are well established within risk science (Aven, 2017; SRA, 2015; Ylönen and Aven, 2023), which could inform a holistic framework for project cost contingency estimation. Hence, this study aims to: 1) build a framework for understanding the risks in project cost contingency estimation; 2) explore the dimensions of elements in project cost contingency estimation based on the framework; and 3) provide research agendas for future research.

The rest of this study is structured as follows. First, the project cost contingency estimation techniques are introduced in Section 2. The research method is then presented in Section 3, explaining how framework synthesis was conducted. Section 4 reports the results of the review, discussing the analysis of the elements during project cost contingency estimation. Section 5 presents the six-element framework. In the end, Section 6 presents the concluding remarks.

2 Project cost contingency estimation techniques

There is no commonly agreed definition of project cost contingency. Various terms are used interchangeably, such as cost contingency, risk contingency, or cost contingency reserve. For instance, Project Management Institute (2017) defines cost contingency as an additional amount added to the baseline cost to cover potential risks and uncertainties. Similarly, Eldosouky *et al*. (2014) define cost contingency reserve as a response to address threats, also called specific risk provision.

Project cost contingency estimation is closely related to various aspects of risks. Numerous estimation techniques have been developed (Ammar *et al*., 2023; Hamid and Kehinde, 2017; Love *et al*., 2015), which can be categorized into risk source assessment and risk event assessment.

Risk source assessment focuses on identifying key risk factors that either increase or decrease the required cost contingency (Figure 1. (a)). Common methods in this category include regression analysis, and artificial neural networks (ANNs), among others. For example, Sonmez *et al*. (2007) applied regression to analyze the relationship between cost contingency and risk sources in highway projects, integrating factors like country risk ratings and contract types. Thal *et al*. (2010) extended this by developing a multiple linear regression model tailored to Air Force construction projects. With the rise of artificial intelligence, ANNs gained attention for contingency prediction due to their ability to model complex, non-linear relationships. Lhee *et al*. (2014) utilized a two-step neural network incorporating project and market factors to calculate contingency reserves for transportation projects. Bae (2024) used feedforward neural networks (FNNs) for the post-construction evaluation of cost contingency amounts to better account for cost risk for future projects. With the large data requirements of ANNs, Arifuzzaman *et al*. (2022) introduced the classification and regression trees (CART) method, which uses readily available project attributes and economic parameters to predict cost contingency across various project stages.

Risk event assessment can be classified into individual risk assessment (Curto *et al*., 2022; Eldosouky *et al*., 2014; Islam *et al*., 2021) and overall risk assessment (Lee *et al*., 2017; Love *et al*., 2015) (see Table 1). Individual risk assessment, from a process perspective, focuses on identifying potential risks and quantifying their impact to estimate cost contingency (Curto *et al*., 2022; Eldosouky *et al*., 2014; Islam *et al*., 2021), as illustrated in Figure 1. (b). For instance, Kwon and Kang (2019) assessed risks like equipment failures and labor cost increases, combining these factors to estimate the project cost contingency. This type of research employs diverse methods that address various aspects of risk assessment. For straightforward probability and risk impact, methods such as the expected value (Eldosouky *et al*., 2014), analytic hierarchy process (AHP) (El-Touny *et al*., 2014; Jung *et al*., 2016), and probability trees (Bakhshi and Touran, 2014; Fu *et al*., 2020) are common for estimating cost contingency. Also, fuzzy theory (Afzal *et al*., 2020; Idrus *et al*., 2011; Jung *et al*., 2016) and simulation tools like Monte Carlo simulations (Afzal *et al*., 2020; Curto *et al*., 2022) are widely used to reduce ambiguity. Additionally, fuzzy Bayesian belief networks have been introduced to contingency estimation by considering risk correlations (Islam *et al*., 2021).

Overall risk assessment takes an outcome perspective to estimate cost contingency, considering the project as a whole and evaluating the combined impact of all risks on project costs (Lee *et al*., 2017; Love *et al*., 2015). Figure 1. (c) illustrates this approach. For example, Love *et al*. (2015) identified the optimal cost contingency by analyzing the project's statistical characteristics and probability distribution of cost overrun. These variables are crucial since cost overrun reflects the cumulative risk impact from various sources. This method determines the required cost contingency by calculating the probability of overall cost overruns. Research in this category focus on how to calculate cost overrun probabilities, often employing probability distributions and simulation tools (Akinradewo *et al*., 2019; Bakhshi and Touran, 2014).

In summary, these studies highlight the importance of the risk perspective in estimating cost contingency (Bakhshi and Touran, 2014; Curto *et al*., 2022; Hoseini *et al*., 2020; Love *et al*., 2015; PMI, 2021; Uzzafer, 2013). Various methods for project cost contingency estimation have been proposed, each focusing on different risk aspects (see Table 1) (Allahaim *et al*., 2016; Hoseini *et al*., 2020).

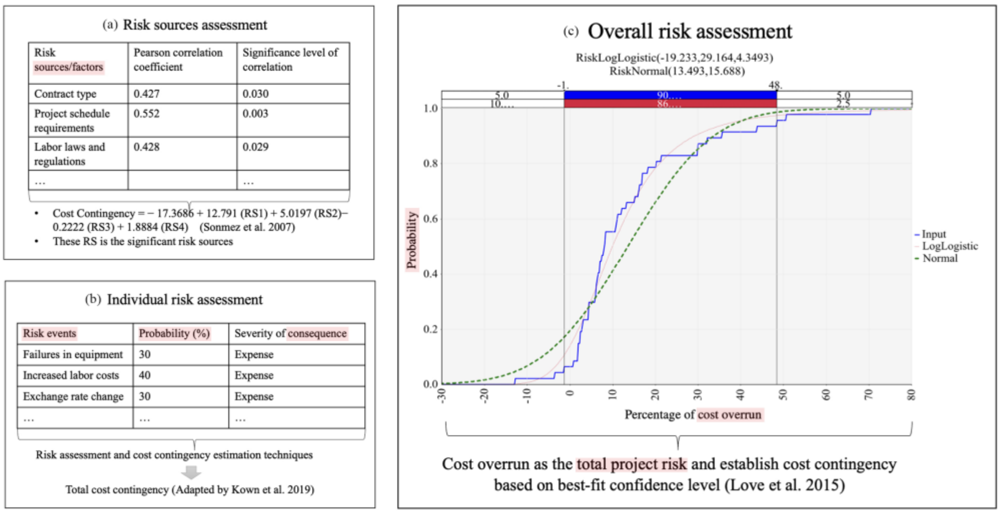

Figure 1. The comparison between three project cost contingency estimation categories

Source: Authors own work

Table 1. The comparison between three project cost contingency estimation categories

Characteristics	**Individual risk assessment**	**Overall risk assessment**	**Risk source assessment**
The type of risk	Specific risk events	Vague risk events	Specific risk sources
Probability level	The probability of each risk event	The probability of overall risk such as cost overrun	Not mentioned
The consequence of risk	Focus on project cost, schedule and other project objectives	Focus on project cost	Focus on cost contingency and project objectives
The source of data	Expert evaluation	Past project data	Past project data

Source: Authors own work

3 Methodology

A framework synthesis method is conducted to review project cost contingency literature (Brunton *et al*., 2020). This method aims to "produce a revised or completely new conceptual framework that reflects the understandings gained from the reviewed literature" (Gough *et al*., 2017, p. 187). The two-phase model suggested by Esterhzy *et al*. (2021) and Gough *et al*. (2017) was adopted: 1) developing an initial framework grounded in existing theories; and 2) conducting a literature search and analysis to establish a new framework, synthesizing insights from both the literature and the initial framework.

3.1 Developing an initial framework

The initial framework development draws on key elements from risk science research (Flage and

Aven, 2009; Ylönen and Aven, 2023). In risk science, definitions of risk contain different elements, as presented in Table 2. Among these definitions, three elements—event (A), consequence (C), and uncertainty (U)—are considered critical. Kaplan and Garrick's (1981) traditional definition represents risk as the triplet (S, C, P), where S stands for the scenario related to events (A), C for its consequences, and P for its probabilities. However, researchers (e.g. Aven and Renn, 2009; Aven, 2017; IRGC, 2005; Rosa, 2003) argue that probability could be replaced by uncertainty, as probability could be seen as one component of uncertainty. Uncertainty encompasses a broader range of factors, including not only the probability of an event but also the lack of knowledge, ambiguity, variability, and unpredictability associated with the risk. In addition, researchers (e.g., Askeland *et al.*, 2017; Marshall *et al.*, 2019) underline the importance of probabilities (P) and knowledge (K) in representing the uncertainties of events and consequences.

While Ylönen and Aven (2023) identified five elements to aid in understanding risk, their study does not establish a framework for exploring interactions among these elements. In this study, an initial five-element framework could be built, which are event (A), consequence (C), uncertainty (U), knowledge (K), and probability (P), as shown in Table 3.

Table 2. The definition of risk

Definition	Elements	Reference
Risk is the combination of probability of an event and its consequences	A, C, P	ISO, 2002
Risk is a situation or event where something of human value (including humans themselves) is at stake and where the outcome is uncertain	A, C, U	Rosa, 2003
Risk is an uncertain consequence of an event or an activity with respect to something that humans value	A, C, U	IRGC, 2005
Risk equals to the two-dimensional combination of events/consequences and associated uncertainties (will the events occur, what will be the consequences)	A, C, U	Aven, 2007
Risk refers to uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value	A, C, U	Aven and Renn, 2009
Risk is uncertainty that matter	C, U	Hillson, 2014
Risk is the consequences of an activity along with the associated uncertainty	A, C, U	SRA, 2015
Risk is the potential of situation or event to impact on the achievement of specific objectives	A, U	APM, 2019

Note. event=A, consequence=C, uncertainty=U, probability=P

Source: Authors own work

Table 3. Elements for risk perspective in literature

Element	Description	Reference

Event	Event is understood as a series of specific occurrences or changes, such as system failures, earthquakes, explosions, or outbreaks of epidemics, or specific changes in world/transaction states	SRA, 2015
Consequence	Consequence refers to the outcome of an event which impacts what humans value	ISO, 2002
Uncertainty	Uncertainty is understood as lack of knowledge about unknown quantities	Flage and Aven, 2009
Probability	Probability is a tool used to express uncertainty about events, consequences and outcomes	Flage and Aven, 2009
Knowledge	Knowledge is defined as justified beliefs and justified true beliefs that are backed up by facts, information, tests, models, and reasoning	SRA, 2015

Source: Authors own work

3.2 Searching and analyzing project cost contingency literature

In the second phase of the framework synthesis, three steps were undertaken, following Denyer and Tranfield (2009) (Figure 2): 1) planning the review and database search; 2) preliminary screening; and 3) content analysis.

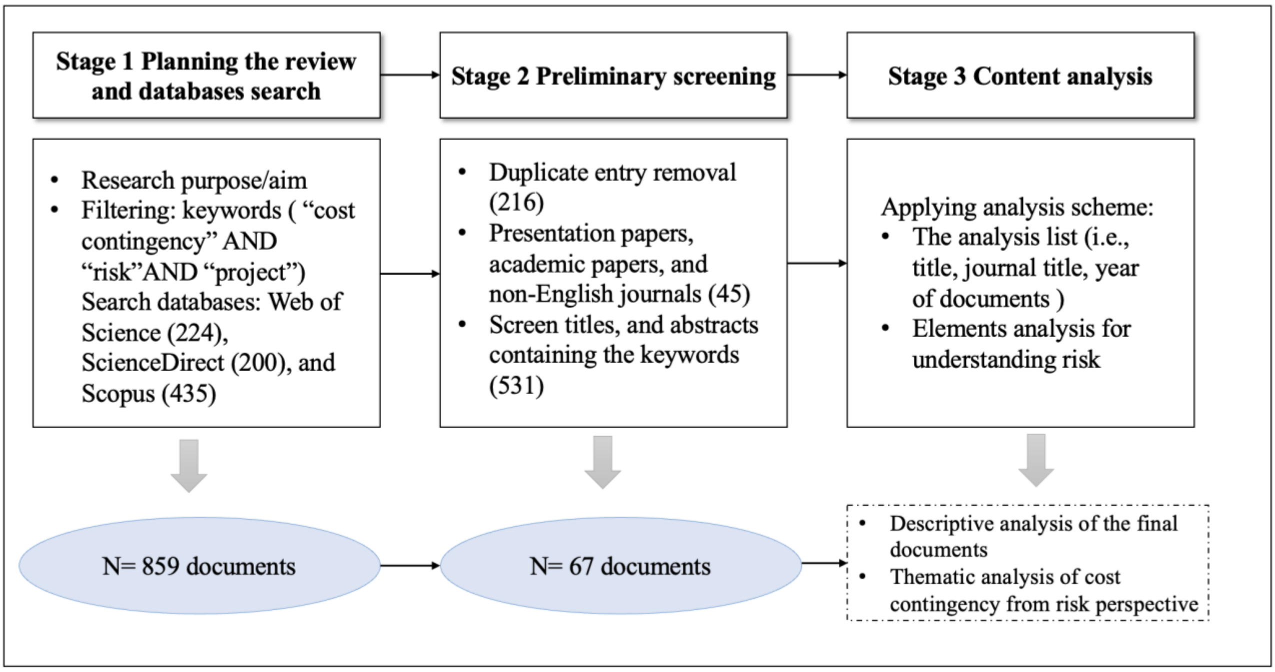

Figure 2. Project cost contingency literature search and analysis

Source: Authors own work

Phase 1. Review planning and database searching. The document search focused on three academic databases—Web of Science, ScienceDirect, and Scopus—using the terms "cost contingency", "risk", and "project" as search guides. Notably, while risk cost and cost contingency are closely related, they are not synonymous in academic discourse, leading to the exclusion of some documents focused solely on risk cost. Additionally, the review was confined to a 22-year period (2002-2024), considering that a majority of influential academic contributions and estimation methods emerged within this timeframe. After restricting the search to English-language articles, a total of 859 documents were selected for this phase.

Phase 2. Preliminary screening. A three-step screening process was implemented. First, the literature from the three databases was imported into Zotero, where the initial screening removed 216 duplicate documents. In the second screening, 45 non-article items (e.g., presentation papers, academic papers and non-English journals) were excluded. The final screening involved title and abstract analysis of the remaining 531 documents. Two criteria were used for abstract analysis: context and topic relevance. Specifically, documents unrelated to project management (e.g., Dissemination of Contingency Management for the Treatment of Opioid Use Disorder) were eliminated. Furthermore, documents were excluded if they did not address cost contingency directly or referenced it only. This process resulted in a final selection of 67 documents.

Phase 3. Content analysis. The content analysis consisted of two parts to identify key themes and patterns in the current research (Elo and Kyngäs, 2008), which were descriptive analysis and thematic analysis. During the descriptive analysis, an analysis guide was established based on the essential data of each chosen document: *document title, journal title, authors and year of documents, the definition of cost contingency, research topic, research methods, research questions, main results, and contributions.* This guide was adapted as the documents were reviewed to align with the research purpose (see Section 5.1). The thematic analysis extended beyond descriptive analysis by delving into the underlying themes and synthesizing the literature. This analysis is guided by elements of risk perspectives.

4. Results of literature review

4.1 General descriptions of the literature

Bibliographic data demonstrates the trends regarding documents across journals (shown in Table 4). By far, the *Journal of Construction Engineering and Management (JCEM) and Journal of Management in Engineering (JME)* can be regarded as the most dominant publication outlets. The vast majority are associated with the research field of construction and engineering.

Table 4. Number of the selected journal documents

Journal title	Number of papers	Percent (%)
Journal of Construction Engineering and Management	10	14.9
Journal of Management in Engineering	5	7.5
International Journal of Construction Management	3	4.5
Journal of Civil Engineering and Management	3	4.5
Automation in Construction	3	4.5
Journal of Information Technology in Construction	3	4.5
Procedia Engineering	3	4.5
Project Management Journal	2	3.0
Journal of Engineering, Project, and Production Management	2	3.0
Engineering, Construction and Architectural Management	2	3.0
International Journal of Managing Projects in Business	2	3.0
Alexandria Engineering Journal	2	3.0
KSCE Journal of Civil Engineering	2	3.0
Others	19	41.8
Total	**67**	**100.0**

Source: Authors own work

The documents can be categorized into three stages along the time dimension (see Figure 3). The first stage is a gradual increase in the annual number of documents between 2002 and 2012. Research primarily focused on simple methods for project cost contingency estimation, such as basic probability models (Touran, 2003), cost standard deviation models (Rothwell, 2005), and linear regression equations (Sonmez *et al*., 2007). After 2010, more advanced methods, like fuzzy expert systems (Idrus *et al*., 2011) and artificial neural networks (ANN) (Lhee *et al*., 2012), were introduced.

The second stage is in 2014. An abrupt rise in documents marked increased attention to factors influencing cost contingency, including contractor perspectives (Enshassi and Ayyash, 2014), upside and downside risks (Eldosouky *et al*., 2014), and application in different contexts, like water infrastructure and highways. Methodological advancements included the shift from basic ANN models to two-step neural networks (Lhee *et al*., 2014).

The third stage is the period of 2015-2024. The number of documents remained steady at 2 to 6 per year until increasing to 8 in 2022. Research during this stage further explored cost contingency methods, combining fuzzy theory with AHP (Afzal *et al*., 2020), improving expected value models (Vegas-Fernández, 2022), and introducing multi-attribute utility theory and AHP (Shash *et al*., 2021) and particle swarm optimization (Kuo *et al*., 2019). Studies also became more comprehensive, examining risk dynamics (De Marco *et al*., 2016), uncertainty types (Curto *et al*., 2022), risk response strategies (Fateminia and Fayek, 2023), and risk correlations (Bae, 2024; Islam *et al*., 2021).

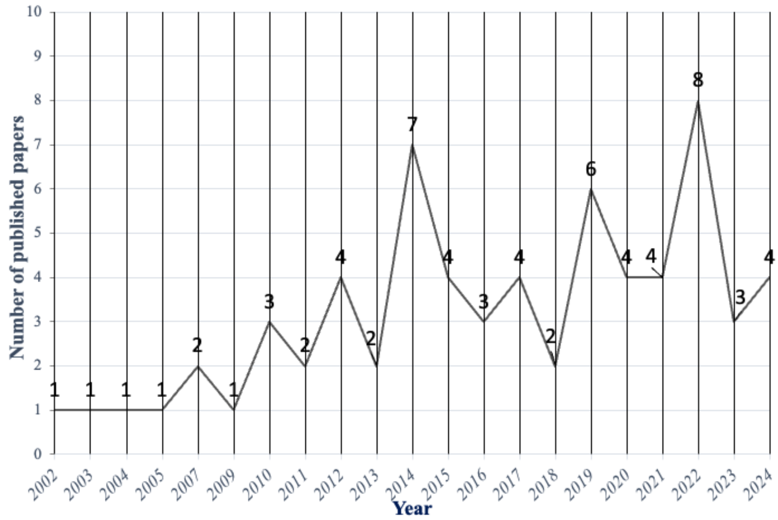

Figure 3. Annual distribution of documents published from 2002 to 2024
Source: Authors own work

The content analysis results presented four research topics (see Figure 4). Project cost contingency estimation is the most frequently discussed topic, representing 73% of the literature. This emphasis provides insights into the project cost contingency estimation process, with Appendix A showing details. The second most prominent topic, cost contingency management (12%), highlights the interrelationship between estimation and management. Some studies focused on dynamic management approaches, utilizing conceptual causal models (Ford, 2002) and system dynamics methodologies (De Marco *et al*., 2016). Other research analyzed management issues from both contractor and client perspectives, revealing an optimism bias in contractors' estimation and management practices (Hoseini *et al*., 2020; Ortiz-González *et al*., 2018).

The third topic is about the factors impacting project cost contingency estimation (9%). Research investigated specific contexts such as Nigeria (Musa *et al*., 2011) and the Middle East (Abdel-Monem *et al*., 2022). Additional research explored these factors from various professional perspectives, including contractors (Enshassi and Ayyash, 2014) and quantity surveyors (Asamoah *et al*., 2023).

The final topic, review/literature review (6%), primarily synthesizes research on project cost contingency from a methodological and tool-oriented perspective (Ammar *et al*., 2023; Bakhshi and Touran, 2014; Hamid and Kehinde, 2017).

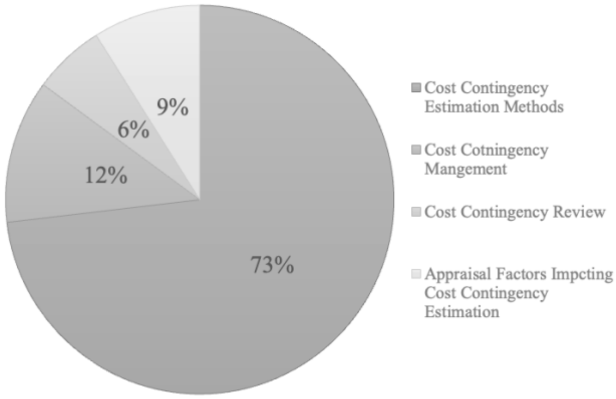

Figure 4. Research topic chosen from the literature relating to cost contingency
Source: Authors own work

4.2 The elements analysis in project cost contingency literature from a risk perspective

Based on the initial framework, the literature analysis was guided by five elements of risk perspective, including (1) event; (2) consequence; (3) uncertainty; (4) probability; and (5) knowledge. As the in-depth analysis of project cost contingency literature, there is an emerging sixth element, mitigation.

4.2.1 Event element of risk in project cost contingency estimation

Events are described as specific occurrences or changes (SRA, 2015). In the context of cost contingency, two dimensions are considered relevant to the element of events, namely the phase of events taking place and the type of events (see Table 5).

(1) Phase of events taking place

Project cost contingency estimation occurs at the design phase (Clark and Lorenzoni, 1985; Love *et al*., 2021), bidding phase (Enshassi and Ayyash, 2014), and construction phase (Hoseini *et al*., 2020). At the design phase, cost contingency is allocated to accommodate design adjustments and changes, addressing factors such as incomplete data, unclear project scope, and imprecise estimation techniques. These factors incur uncertainties that affect the accuracy of cost estimation.

During the bidding phase, it is essential to consider events from the bidder's perspective. Various events impact cost contingency, such as bid preparation time, accurate contracting costs, and the specific risks associated with the bidding process. For instance, Enshassi and Ayyash (2014) discussed how insufficient time for bid preparation can lead to incorrect contracting costs.

During the construction phase, cost contingency is allocated to account for changes and unresolved design issues that emerge. It helps address uncertainties during the construction process, including site limitations and adverse weather conditions (Hoseini *et al*., 2020; Love *et al*., 2021).

(2) Event types

Three types of events were identified, namely underlying risk sources, direct risk events, and residual and secondary risk events. Underlying risk sources are the causes that contribute to the occurrence of risk events (De Marco *et al*., 2016; Hollmann 2008). They impact projects by disrupting the development of activities, leading to variations in the anticipated duration and cost estimates (Eldosouky *et al*., 2014). Identifying risk sources is essential for enhancing the accuracy of project cost contingency estimation (Lam *et al*., 2017; Lhee *et al*., 2014; Sonmez *et al*., 2007). For example, Lhee *et al*. (2014) estimated the cost contingency by considering input risk sources—such as project types, road surface type, road condition, accessibility, weather conditions, location name, and the total activity cost—based on historical data for each road activity.

Direct risk events are defined as the occurrence of a particular set of circumstances (ISO, 2002), triggered by risk sources. In project cost contingency estimation, these events are more specific compared with the broader risk sources. For example, Eldosouky *et al*. (2014) developed a model to quantify events linked to particular sources, such as site mobilization delays (an event) caused by contractor or manager errors (a risk source). Similarly, Kumar *et al*., (2021) demonstrated claim documents from past projects as one potential source of risk.

According to Kown and Kang (2019), accurate project cost contingency estimation also covers residual and secondary risk events beyond the initially identified. Residual risk refers to the remaining risk level after applying risk strategies to reduce natural risks (Ahmadi-Javid *et al*., 2020). Secondary risk arises as a direct consequence of implementing a risk strategy (PMI, 2021). Fateminia and Fayek (2023) state that including a contingency amount in the project budget is one way to address potential secondary risks, indicating that risk and cost contingency should be re-evaluated following the development of a risk response strategy.

In different contexts, risk events vary according to the nature of the project. In Engineering, Procurement, and Construction (EPC) projects, integrated risks between design, procurement, and construction should be considered (De Marco *et al*., 2016). In residential projects exposed to environmental disasters, risks related to hazards like floods, geography, and climate should be included (Van *et al*., 2019). For transportation projects, the complexity of construction environments, larger investments, extended timelines, and strict regulatory requirements result in unique risks, such as traffic management during construction and geological conditions (Bae, 2024; Diab *et al*., 2017; Olumide *et al*., 2010). For power projects, given the extended construction timelines, events such as inflation risks, inaccurate soil surveys, and equipment failures need to be accounted for (Arifuzzaman *et al*., 2022; Islam *et al*., 2021). International projects, on the other hand, are subject to risks including political instability and foreign exchange fluctuations (Sonmez *et al*., 2007). In software development projects, typical risk events involve highly technical issues such as changes in requirements, system defects, or incorrect technological choices (Uzzafer, 2013).

Table 5. Phase of events taking place and type of events in project cost contingency literature

Dimension	**Category**	**Reference**	**Event example**
The phase of event	The design phase	Eldosouky *et al*., 2014; Enshassi and Ayyash, 2014	- Discordant design - Design complexity - Design quality
	The bidding phase	Eldosouky *et al*., 2014; Enshassi and Ayyash, 2014; Sonmez *et al*., 2007	- The level of competition in bid - Type of contract currency - Insufficient time for bit estimation - Inappropriateness of specifications
	The construction phase	Eldosouky *et al*., 2014; Enshassi and Ayyash, 2014; Hoseini *et al.,* 2020; Idrus *et al*., 2011; Islam *et al*., 2021	- Site limitation - Mistakes during construction - Variation orders - Change in the scope/ design/specification of the project
The type of event	Underlying risk source	Eldosouky *et al*., 2014; Enshassi and Ayyash, 2014; Idrus *et al*., 2011	- Project size - The requirements of project schedule - Project types - Weather - Design product
	Direct risk event	Curto *et al*., 2022; Eldosouky *et al*., 2014; Hoseini *et al*., 2020; Islam *et al*., 2021; Kwon and Kang, 2019; Mancini *et al*., 2022; Uzzafer, 2013	- Unclear arbitration procedure - Delay problems - High workload - Absence of prior experience - Changes in requirements
	Residual and secondary risk event	Fateminia and Fayek, 2023; Kwon and Kang, 2019; Liu and Napier, 2010	- The events occurring after certain risk strategies - The remaining events that cannot be eliminated by risk strategies

Source: Authors own work

4.2.2 Consequence element of risk in project cost contingency estimation

The second element is consequence, which refers to the outcome of a risk event (ISO, 2002). Consequences impact several aspects, including cost, duration, quality, scope, and the breakdown of activities or work packages (Seyedhoseini *et al*., 2009). In the project cost contingency context, consequences are related to project objectives. Content analysis results revealed two primary dimensions for categorizing consequences: consequence type and consequence feature.

(1) The type of consequence

Three main categories of project cost contingency estimation focus on different consequences. Overall risk assessment focuses on the impact of events on total project cost (e.g., Baccarini and Love, 2014; Enshassi and Ayyash, 2014; Love *et al*., 2015). For example, Love *et al*. (2015) adapted the cumulative distribution function to determine the realistic probability of a cost overrun, utilizing the cost consequence of overall risk as an appropriate cost contingency.

Individual risk assessment considers consequences on cost and other objectives like schedule and quality (Curto *et al*., 2022; De Marco *et al*., 2016). For instance, Curto *et al*. (2022) identified risk events using the three criteria, such as delayed days, the amount of cost, and the impact on overall function.

Risk source assessment focuses on consequences related to cost contingency. Sonmez *et al*. (2007) used regression to identify risk factors affecting cost contingency. Lhee *et al*. (2014) also explored factors like design-build contracts and construction time to impact cost contingency using an ANN-based model.

In various fields, the focus on the consequences of risk in cost contingencies remains consistent, often concentrating on single or multiple consequences on cost, schedule, quality, or activities. In the construction industry, the consequences of risks are most often evaluated in terms of cost and schedule. Eldosouky *et al*. (2014) noted that the first step in developing a project risk model is estimating the variability in cost and schedule. In software development with a high degree of innovation, contingencies must also account for risks associated with project scope changes that may lead to cost overruns (Uzzafer, 2013).

(2) Positive or negative consequences

Most project cost contingency estimation methods examine the undesirable or negative consequences of events, while only a few, such as Eldosouky *et al*. (2014), focus on the consequence of the events that could also be desirable or positive. Potential positive consequences of events could reduce an estimate of the amount of budget if they are exploited. This perspective guides estimating cost contingency based on individual risk assessment and risk source assessment, emphasizing the need to identify each event considering both features.

From the perspective of overall risk assessment, research mainly focus on the negative consequences of cost. For example, Hammad *et al*. (2016) presented the Monte Carlo simulation (MCS) model to estimate cost contingency by calculating the probability of a cost overrun (a negative consequence) caused by total project risks.

4.2.3 Uncertainty element of risk in project cost contingency estimation

Uncertainty is understood as a lack of knowledge about unknown quantities such as events and consequences (Flage and Aven, 2009). Uncertainty could be divided into two dimensions, namely the uncertainty type and the measurement method.

(1) The uncertainty type

There are three types of uncertainties covered in the project cost contingency estimation, which are aleatory, epistemic, and stochastic uncertainties (Table 6). Stochastic uncertainty affects both the occurrence of events and their outcomes, whereas epistemic and aleatory uncertainty is primarily concerned with project consequences, independent of specific event occurrences (Curto *et al*. 2022; Hillson, 2014).

Stochastic uncertainty, also known as event uncertainty, is predicated on the occurrence of events with known outcomes (Hillson, 2020). This uncertainty relates to whether an event (A) will occur and, if so, what its consequences will be.

Epistemic uncertainty is influenced by factors such as information availability, expertise, and beliefs and relates to a lack of knowledge or subjectivity (Elms, 2004; Hillson, 2014). This uncertainty affects project consequences (C), where a lack of information or understanding can lead to poor decision-making. For instance, in energy projects, cognitive uncertainty may stem from inaccurate predictions of energy demand or insufficient mastery of new technologies (Islam *et al*., 2021;

Plebankiewicz *et al*., 2021).

Aleatory uncertainty characterizes the inherent randomness and unpredictability in various physical processes, such as unpredictable weather conditions and the probability of hardware malfunctions due to aging (Elms, 2004; Hillson, 2014). This uncertainty affects project outcomes by introducing variability through natural processes or system uncertainties. Curto *et al*. (2022) identified variability in labor, materials, equipment, and weather conditions as sources of stochastic uncertainty.

Current research on contingency estimation tends to focus more on event uncertainty, particularly in construction projects where delays and material shortages are common. Some scholars argue that aleatory uncertainty, such as estimation errors and productivity rates, are often overlooked in the contingency calculation (Eldosouky *et al*., 2014). Curto *et al*. (2022) thus advocate for incorporating all three types of uncertainty into cost contingency.

The emphasis on these uncertainties varies across different types of projects. In construction and transportation projects, early cost estimates often include significant uncertainty due to a lack of project-specific information at the early stages (Sonmez *et al*., 2007). Event and aleatory uncertainties are important, as unforeseen events (e.g., accidents, equipment failures) and environmental randomness (e.g., weather fluctuations, material quality variations) impact project outcomes. In contrast, energy projects prioritize cognitive uncertainty, as they involve complex technologies and policy considerations, where inaccurate information or judgments can lead to substantial decision-making errors (Islam *et al*., 2021). Similarly, software projects are affected by cognitive uncertainty, where misunderstandings of technology and requirements can hinder project success (Uzzafer, 2013).

Table 6. The type of uncertainty in project cost contingency literature

Type of uncertainty	**Definition**	**Reference**
Aleatoric uncertainty	Spurred on by the intrinsic variability of natural phenomena as a result of several contributing factors.	Baccarini and Love, 2014; Curto *et al*., 2022; Islam *et al*., 2021; Liu and Napier, 2010
Epistemic uncertainty	Absence of information and understanding regarding a system or its surroundings	Afzal *et al*., 2020; Curto *et al.,* 2022; Islam *et al.,* 2021; Plebankiewicz, 2021; Popescu *et al.,* 2003
Stochastic uncertainty or event uncertainty	The events with known outcomes could be occurred stochastically	Curto *et al*., 2022; Eldosouky *et al*., 2014; Islam *et al*., 2021; Jung *et al*., 2016

Source: Authors own work

(2) The measurement method

In project cost contingency estimation, different types of uncertainty—aleatoric, stochastic (event), and epistemic uncertainty—require distinct measurement methods. Specific tools are needed to measure these uncertainties. Common measurement methods in project cost contingency literature include probability distribution, fuzzy logic-based approaches, Bayesian Network, and Monte Carlo simulation (see Table 7).

For event uncertainty, tools such as probability trees (Fu *et al*., 2020), analytic hierarchy process (AHP) (Afzal *et al*., 2020; Shash *et al*., 2021), and Bayesian networks (Islam *et al*., 2021) are employed. These tools, combined with Monte Carlo simulation, can predict both the probability and impact of events. Aleatoric uncertainty, on the other hand, is managed through probability distribution analysis (Eldosouky *et al*., 2014; Para-González, 2018) or Monte Carlo simulation (Chang and Ko, 2017). In construction and transportation projects, historical data is often used to model the probability of accidents or delays, providing a foundation for estimating contingency costs related to event uncertainty (Bae, 2024; Love *et al*., 2015).

Epistemic uncertainty, arising from insufficient information, lack of knowledge, or inconsistent expert judgment, is managed using fuzzy logic. Fuzzy logic processes imprecise information and subjective judgments using fuzzy sets and membership functions, making it well-suited for less quantifiable situations. It provides a qualitative, language-based risk assessment method (Jung *et al*., 2016; Siraj and Fayek, 2021).

Table 7. Methods for measuring uncertainty in project cost contingency estimation

Method	Benefit	Uncertainty	Reference
Probability distribution	- Probability distribution is advantageous for modeling uncertainty - The occurrence probability percentage could be accurately represented	Aleatoric uncertainty; Stochastic uncertainty	Akinradewo *et al*., 2019; Bakhshi and Touran, 2014; Curto *et al*., 2022
Fuzzy theory	- The fuzzy method emerges as a valuable approach to overcoming the drawbacks of probabilistic methods, giving experts more freedom to communicate knowledge based on experience and intuition. - In contrast to probabilistic methods, the fuzzy method doesn't necessitate historical data records or a large number of simulations	Epistemic uncertainty	Afzal *et al*., 2020; Idrus *et al*., 2011; Islam *et al*., 2021; Jung *et al*., 2016; Mancini *et al*., 2022
Bayesian belief network	- Excels in dealing with cause-effect relationships and aids in making decisions in the face of uncertainty - BBN is especially useful in situations where the relationships among events are complex and uncertain	Stochastic uncertainty	Islam *et al*., 2021; Le´sniak *et al*., 2020; Leu *et al*., 2023

Monte Carlo simulation (MCS)	- MSC has been identified as one of the most effective. It stands out due to its simplicity, ease of use, and comprehensibility - MSC not only analyzes risks but also considers opportunities and uncertainties, enabling decision-making under uncertainty.	Aleatoric uncertainty; Stochastic uncertainty	Akinradewo, 2019; Curto *et al*., 2022; Eldosouky *et al*., 2014

Source: Authors own work

4.2.4 Probability element of risk in project cost contingency estimation

Probability serves as a valuable tool for expressing uncertainty related to events and their consequences (Aven, 2012). The probabilities element from content analysis can be delineated along two dimensions, including the type and the expression method of probability.

(1) Type of probability

In project cost contingency estimation, two types of probability are commonly discussed: individual risk events and overall project risk. Individual risk assessment implies the estimation of the possibilities of specific events. For example, Jung *et al.* (2016) analyzed the probability of different events, such as poor communication, rework due to contractor's fault, and delay in financing by clients. The overall risk assessment emphasized the total impact of consequences triggered by these events on project objectives, such as the probability of cost overrun, project schedule delay, and rework. Baccarini and Love (2014) utilized the probability distribution of cost overrun stemming from various risks to estimate cost contingency.

(2) The expression method of probability

Probabilistic expressions in the project cost contingency literature encompass a range of methods, such as probabilities, prediction intervals, probability distributions, and expected values (Flage and Aven, 2009). These methods are employed to represent the degree of uncertainty regarding the likelihood of an event occurring or its potential consequences.

Probabilities are often used when sufficient project data are available to assess the events, which can be expressed as percentages, fractions, or decimal values, indicating the likelihood of an event occurring. For example, Islam *et al*., (2021) collected project risk data, assigning probabilities to four specific risk events within their project, with likelihoods ranging from 0.35 to 0.69. These probabilities could quantify the uncertainty of each risk event.

When it is not feasible to provide a precise numerical value for probability, intervals are employed to represent the uncertainty. These intervals are project-specific. Curto *et al*. (2022) referred to a method for defining scales of probability and impact from the Project Management Institute (2017), such as a high scale presenting the probability value between 51-70%, impacting time within 1-3 months.

Probability distributions are commonly used to present the uncertainty of risk. Baccarini and Love (2014) demonstrated that a probability function (Wakeby) provides the most comprehensive distribution fit for calculating the probability of cost contingency. In addition, expected values (EV) are another probabilistic expression that represents the average outcome or expected outcome of an event. It combines the probabilities of different outcomes with their associated values to calculate the overall expected value. Vegas-Fernández (2022) examined the positive and negative impacts of using expected values (EVs) in project cost contingency estimation and proposed a novel direction for improvement.

4.2.5 Knowledge element of risk in project cost contingency estimation

When assessing uncertainties related to events and their consequences, it is crucial to show how knowledge supports those probabilities. Content analysis results have identified two dimensions in this regard, which are the type and strength of knowledge.

(1) The type of knowledge

Different types of knowledge are discussed in the project cost contingency literature, including justified true beliefs (objective) and justified beliefs (subjective). Objective knowledge encompasses verifiable facts and evidence, such as historical performance data and project information. In projects with abundant historical data, objective knowledge plays a critical role in risk estimation. For example, Baccarini and Love (2014) employed objective knowledge, leveraging statistical analysis with cost information derived from reports from the Australian water governments. However, a significant constraint lies in the availability of previous cost data for comparable projects. Variations in the organizational, project-related, and environmental factors are another limitation (Love *et al*., 2015). For software projects or regional projects where historical data may be limited—especially in cases involving new technologies or unfamiliar regions—the availability of objective knowledge is often constrained. Thus, subjective knowledge could be an important input for assisting cost contingency calculation, mainly from expert judgment, questionnaires, and interviews (Idrus *et al*., 2011).

(2) The strength of knowledge

The strength of knowledge refers to the quality and reliability of the available knowledge. It involves assessing various factors (Askeland *et al.*, 2017; Aven, 2017), such as the availability and reliability of data, the reasonability of assumptions, and agreement among different sources.

The strength of knowledge relates to the reliability of the data source and the level of agreement among experts. Several studies have addressed these aspects. For example, Lhee *et al*. (2014) collected data from 495 completed projects of the Florida Department of Transportation (FDOT) between 2004 and 2006 to develop an artificial neural network (ANN) estimator for contingency-related data. Islam *et al*. (2021) presented a modified model where experts were assigned different weights based on their status, experience, and other relevant factors. This approach acknowledges a varying level of expertise among experts and considers their individual contributions to the estimation process.

4.2.6 The Mitigation element of risk in project cost contingency estimation

Mitigation involves assessing risk response that can be employed to mitigate risks (Fateminia and Fayek, 2023). This helps in prioritizing resources and optimizing the distribution of cost contingency to address the most critical risks. The content analysis has identified two dimensions, i.e., the role and type of risk response.

(1) The necessity of mitigation in project cost contingency

Cost contingencies are allocated for implementing risk response actions, and managing secondary and residual risks (Fateminia and Fayek, 2023; PMI, 2013). Additionally, they are often used to cover risks that remain after project mitigation efforts (APM, 2008; Eldosouky *et al*., 2014). These imply a need to assess the risk mitigation measures before determining the necessary costs for managing them.

De Marco *et al*. (2023) argue that cost contingency integrates proactive and reactive risk management strategies. In proactive risk management, project managers preemptively use cost contingency to mitigate risks early (Ford, 2002), reducing future consequences and additional costs. In contrast, reactive management disregards risks initially, addressing them later with larger reserves (De Marco *et al*., 2016).

(2) The role of risk response

Risk response plays a critical role in adjusting cost contingency estimates. For example, Eldosouky *et al*. (2014) proposed a three-round Monte Carlo Simulation (MCS) approach, which highlights the importance of selecting and implementing response strategies to mitigate threats and capitalize on opportunities in project cost contingency estimation. Similarly, Islam *et al*. (2021) introduced the Agreement Index (AI) analysis, which applies appropriate risk management policies to control risks and reallocate contingency costs.

(3) The type of risk response

There are two types of risk response strategies for project cost contingency estimation, namely risk prevention and risk adaptation. Risk prevention involves measures to decrease the likelihood of risk events, such as gathering more information and hiring experienced project managers. On the other hand, risk adaptation focuses on mitigating and minimizing the negative consequences of risk events (Fan, 2008). For example, Kuo *et al*. (2019) formulated cost contingency by considering two distinct response strategies, with risk adaptation further divided into strategies addressing schedule impacts and delay-related monetary losses.

5 The six-element framework for understanding risks in project cost contingency estimation

The literature review reveals six elements for understanding risks in project cost contingency estimation, namely event, consequence, uncertainty, probability, knowledge, and mitigation. Based on these findings, a six-element framework is developed to provide a holistic view of risk in project cost contingency estimation (Figure 5).

The relationship between event, consequence, and uncertainty is key for identifying risks. The event element represents the occurrence of the potential risk. These events are pivotal as they trigger the consequences—the impact or outcome of events, encompassing impacts on time, cost, and quality. Central to this framework is uncertainty, which bridges events and consequences by incorporating the type and nature of unpredictability involved. This uncertainty poses a significant challenge in estimating project cost contingency. Specifically, the types and phases of events are often unpredictable (Curto *et al*., 2022), and the diversity of consequence types complicates the accurate estimation of potential risks and losses.

Probability and knowledge provide the informational and quantifiable bases for risk assessment. Probability quantifies the likelihood of the event occurrence and its potential consequences, which rely on the strength of available knowledge, whether subjective or objective. By providing a numerical measure, probability transfers the qualitative aspects of uncertainty into a numerical form.

Mitigation focuses on the strategies and actions to manage and reduce identified risks, playing an important role in adjusting or establishing project cost contingency (Eldosouky *et al*., 2014; Fateminia and Fayek, 2023). Probability and knowledge serve as tools to evaluate these mitigation strategies.

The developed six-element framework offers a holistic approach to integrate risk management into the project cost contingency estimation. By continuously monitoring and updating the six elements, project managers can dynamically adjust cost contingencies in response to emerging risks and changing project conditions.

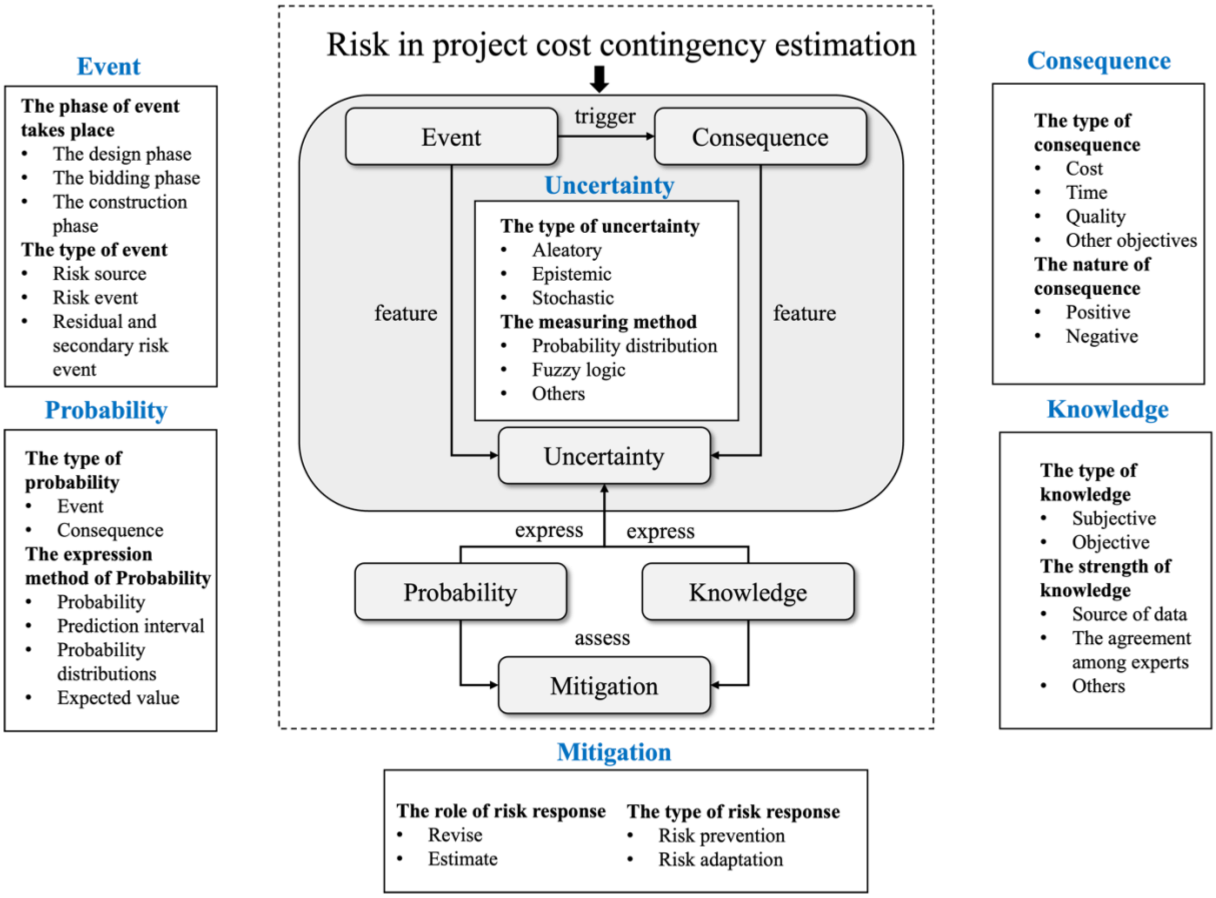

Figure 5. The six-element framework for understanding risks of project cost contingency estimation

Source: Authors own work

6 Conclusion

This study provides a six-element framework for risk identification, which guides the project cost contingency estimation. The twelve dimensions related to these elements clarify the scope of project cost contingency estimation, providing a nuanced understanding of influencing factors to enhance project cost contingency estimation precision.

6.1 Implications for research and practice

This study expands the knowledge of project cost contingency by developing a six-element framework. By incorporating these diverse risk elements into a unified framework, this study could address the contradictions and inconsistencies in project cost contingency estimation. Furthermore, a six-element risk framework present a holistic framework to understanding risks for project cost contingency estimation.

Furthermore, this study distinguishes cost continency estimation methods based on risk perspective, namely different elements. Previous research classifies these methods by tools such as deterministic, probabilistic, mathematical, and AI-based approaches (Bakhshi and Touran, 2014; Love *et al*., 2021). Differing from these studies, this study presents a six-element framework, which could enrich the understanding of the project cost contingency estimation process.

The findings of this study can also provide guidance for practitioners with a structured approach for identifying and assessing risks in project cost contingency estimation. The proposed framework elucidates the complex relationships among different risk elements. For example, in a construction project, encountering unexpected soil conditions during excavation can be identified and analyzed using the framework. It assesses potential negative consequences (e.g., project delays, increased costs) and uncertainties (e.g., the extent of soil remediation, impact on the timeline). By incorporating probability, historical knowledge, and mitigation, the framework allows for a precise estimation of necessary project cost contingencies, enhancing the accuracy and reliability of project management outcome.

6.2 Research agenda

This study proposes four research agendas based on the systematic literature review.

(1) The knowledge dimension

Subjective or objective knowledge has a significant impact on the accuracy of project cost contingency estimation (Idrus *et al*.,2011; Islam *et al*., 2021; Love *et al*., 2015; Mancini *et al*., 2022). Evaluation criteria for the knowledge dimension should be explicitly presented, such as the availability and reliability of data, the reasonability of assumptions, and the agreement among experts (Askeland *et al.*, 2017). Although researchers have created assessment models to determine how to rank experts according to various weights (e.g. Islam *et al*., 2021), other criteria for assessing knowledge strength remain scarce. Future research is recommended to examine how to present the knowledge dimension in the project cost contingency estimation.

(2) Cost contingency allocation and management

A promising area for further research is to examine the process of cost contingency allocation and management based on the six-element framework. There are plentiful articles estimating cost contingency by risk analysis, while few articles examine how to allocate the cost contingency during the project execution. The six-element framework serves as valuable guidance through connecting project activities and risks to allocate and manage cost contingency.

(3) The weight of each element related to risk in project cost contingency

In establishing project cost contingency, the weights of various elements can be adjusted to reflect the project's specific characteristics. For instance, research and development (R&D) projects are characterized by high risks, making it crucial to prioritize and increase the weight of the uncertainty element in contingency planning.

(4) Empirical studies testing the framework

The six-element framework is established through the literature review. Future studies could empirically test its effectiveness. This would further reinforce the application of the framework and contribute to both theoretical and practical advancements in project cost contingency estimation.

6.3 Limitations

Two limitations are present in this study. Firstly, some references related to cost contingency may have been omitted due to the selection of keywords and criteria, including a focus on English-language documents to ensure accessibility and comparability, as well as high-ranked academic journals to maintain source quality and reliability. An additional limitation of this study is the lack of consideration of regulations related to project cost management and cost contingency. Such regulatory variations may introduce region-specific dimensions that could more precisely guide project practices.

Appendix. The project cost contingency estimation research

Reference	Estimation technique	Description for risk in project cost contingency estimation	Context
Touran, 2003	Probabilistic analysis	The probability of a cost overrun is calculated as a function of a contingency percentage	Construction project
Han and Park, 2004	Risk analysis and categorical relationship-based approach	Use categorical relationship-based method as a risk analysis tool, specific risk like political condition (bad, average and good)	Construction project
Rothwell, 2005	Probability analysis	Cost contingency as the standard deviation of the cost estimate	Project
Barrza and Bueno, 2007	Monte Carlo simulation	Cost contingencies have the objective of covering probable cost increases (risks) above target estimates	Project
Sonmez *et al*., 2007	Regression analysis	Consider the factors creating risk in construction projects and impacting cost contingency	International projects
Chou *et al*., 2009	Monte Carlo simulation	Cumulative distribution functions (CDFs) of cost can be used to assess project risks	Engineering project
Liu and Napier, 2010	Risk analysis	Inherent risks, contingent risk events and residual risks	Water infrastructure project
Thal *et al*., 2010	Multiple linear regression model	Risk sources identified in the literature as having an impact on either contingency estimates or cost overruns	Air force construction project
Olumide *et al*. 2010	The delphi method and sliding-scale contingency graphs	A total project cost estimate is composed of a base estimate of known costs and a contingency estimate of risk costs	Highway projects
Idrus *et al*., 2011	Risk analysis and fuzzy expert	The risk analysis and assignment of associated contingency	Construction project
Lhee *et al*., 2012, 2014	Artificial neural networks	Input parameters for contingency model including project factors, market factors and other factors	Construction project
Uzzafer, 2013	Risk analysis and probabilistic analysis	The contingency estimation is defined as the buffer between the expected cost of the project and the expected cost due to the maximum impacts of risk events	Software projects
Baccarini and Love, 2014 and Love *et al*., 2015	Probability analysis	Calculate the project cost overrun brought by project overall risks	Transport projects

Bekker. 2014	The neural network and expected value analysis	Expected value analysis is used in a risk register employing a binomial distribution to estimate the number of risks expected	Construction projects portfolio
Eldosouky *et al*., 2014	Risk analysis and Monte Carlo simulation	Risk as uncertain event or condition	Construction project
El-Touny *et al*., 2014	Analytic hierarchy processes (AHP)	The risk events during the bidding stages that affect cost contingency	Construction project
Jung *et al*., 2016	Analytic hierarchy processes and fuzzy theory	Identifying various risk events causing the project cost overrun	Construction project
Salah and Moselhi, 2015	Fuzzy theory and probability analysis	Assess risks associated with the project using fuzzy numbers	Construction project
Touran and Liu, 2015	Probability analysis	Minimizing the effect of bias in the calculation of total costs as cost contingency	Construction project
Shrestha and Shrestha, 2016	Artificial neural networks	Input parameters such as work category, road surface type, road condition, accessibility, weather condition, location name, and the total activity cost	Road maintenance project
Chang and Ko, 2017	Monte Carlo simulation	Using the expert's assessment as input of financial impact and occurrence likelihood of individual risks in model	Construction project
Diab *et al*., 2017	Regression analysis	Risk drivers are the critical causes of risk events	Highway projects
Lam *et al*., 2017	Combined qualitative–quantitative exploratory methods	Identifies the risk factors influencing the contingency sum	Construction project
Para-González *et al*., 2018	Monte Carlo Simulation	Monte Carlo method will be employed by using different probabilistic distributions for cost estimation	Ferry construction project
Kuo *et al*., 2019	Expected monetary value and particle swarm optimization (PSO) algorithm	Expected monetary value to calculate the contingency cost which is a multiplication of risk probability and loss	Engineering, procurement, and construction project
Kwon *et al*., 2019	Risk analysis, the three-point estimation technique and R-value	Identified and unidentified risks	Building project
Ou-Yang *et al*., 2019	Monte Carlo simulation	Identify risk events in project cost contingency estimation	Engineering, procurement, and construction project
Traynor and Mahmoodian, 2019	Monte Carlo simulation	Risk contingency is the provision of an estimated amount of monetary value to cover uncertainties or unpredictable events	Project
Van *et al*., 2019	Multiple regression analysis	Identifying risks significantly affecting the cost of projects is necessary	Residential construction projects
Afzal *et al*., 2020	Fuzzy-AHP and Monte Carlo simulation	Potential risks breakdown structure for cost overrun	Metropolitan project

Hoseini *et al*., 2020	Risk analysis	Risks are the events that can be identified and may or may not occur in a project	Construction project
Moselhi *et al*., 2020	Monte Carlo method and fuzzy theory	Calculation of total standard deviation of project cost	Construction project
Islam *et al*., 2021	Risk analysis, fuzzy expert, and Bayesian belief rework	Project risks of the cost overrun	Plant project
Love *et al*., 2021	Heuristics method	In risk settings, all the relevant alternatives, consequences, and probabilities can be known	Transport projects
Shash *et al*., 2021	Analytical hierarchy process and multi attribute utility theory	Risk factors and events can be considered as attributes or criteria impacting cost contingency	Construction project
Siraj and Fayek, 2021	Hybrid fuzzy system dynamics model	Analyze the impacts of interrelated and interacting risk and opportunity events to project contingencies	Construction project
Arifuzzaman *et al*., 2022	Classification and regression tree (CART)	Input variables as location, inflation rate, plant type, project cost	Power plant project
Curto *et al*., 2022	Risk analysis and Monte Carlo simulation	A list of risks can affect the project's time and cost objectives	Construction project
El-Kholy *et al*. 2022	Artificial neural networks and regression-based models	Input information of 30 projects, such as year, building area, duration, project cost	Building projects
Fateminia and Fayek, 2023	Risk analysis and hybrid fuzzy methods	Risk events that are responded to with proactive response actions or active acceptance response actions	Construction project
Mancini and Roghabadi, 2022	Risk analysis, fuzzy expert and Bayesian belief rework	Identifying an optimal set of risk mitigation actions, and predicting the additional project delay or cost based on a quantitative risk analysis	Nuclear decommissioning projects
Paquin *et al*., 2022	The coherent risk measure	Project cost probability distributions for determining cost overrun contingency reserve	Project
Vegas-Fernández, 2022	Expected value and Monte Carlo simulation	Risk events with a defined risk cost can be considered when it comes to calculating project risk cost	Project
Sihombing and Christin, 2023	Risk analysis and Monte Carlo simulation	The risk factors affecting contingency costs	Pipeline EPC project
Bae, 2024	Feedforward neural networks (FNNs)	Using a curve-fitting technique for the post-construction evaluation of cost contingency amounts to cover cost risk for future projects	Transportation project
Curto *et al*., 2024	Risk analysis and Monte Carlo simulation	This risk register data includes the probability of each risk materializing and its potential influence on the cost of the activity	Construction project
Ko *et al*.2024	Risk management tools and fuzzy theory	Significant risks affecting construction cost contingencies were identified, prioritized, and then mapped with common project types	Transportation infrastructure project

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