Cash flow risk management across multiple construction projects using value at risk

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Abstract

Purpose: Managing cash flow risk across multiple concurrent construction projects presents significant challenges due to inherent uncertainties and complexities, which can jeopardize a company's financial stability and project success. This research aims to develop a robust and reliable model for effective cash flow prediction and risk management in the construction industry.

Design/methodology/approach: We propose a novel framework that integrates value at risk (VaR) with simulation-based optimization techniques to quantify and manage the impact of various financial risks on cash flow across multiple projects. This robust predictive method combines theoretical and practical approaches, advancing existing cash flow management practices in construction project management and finance.

Findings: The study demonstrates that traditional cash flow management methods often fail to account for the cumulative risks in multi-project environments. Our approach effectively mitigates the adverse effects of financial volatility by providing a probabilistic assessment of potential losses, ensuring alignment of cash flows with established baselines and thereby improving project outcomes and financial resilience.

Originality/value: This research makes a significant contribution by introducing an innovative method that applies VaR to construction cash flow management for multiple concurrent projects – a novel application in this context. By addressing the major difficulties of quantifying and managing financial risks in complex project portfolios, our approach offers new insights and practical tools for enhancing financial planning, risk management and overall resilience in the construction industry.

Keywords: Cash flow, Value at risk, Construction project, Risk management, Simulation-based optimization

1. Introduction

The construction sector is characterized by its complexity and the multitude of factors that influence project outcomes. Among these, cash flow management stands out as a critical determinant of a contractor's success or failure. Contractors who lack sufficient cash to support the timing of their operations often find themselves forced to alter their plans by delaying or temporarily suspending activities. This disruption can lead to missed project deadlines, increased costs, and even project failure (Al-Shihabi and AlDurgam, 2020). A primary cause of this issue is the imbalance of cash inflows and outflows during project periods, exacerbated by advanced payments withheld by employers to ensure proper project execution. Over-reliance on these payments can result in deficits and financial difficulties, potentially halting project work altogether. Consequently, contractors are often compelled to use their capital or borrow funds to finance their projects (Alavipour and Arditi, 2018).

Proper cash flow management is essential for the survival of construction businesses. It involves a meticulous balance of revenue and expenditure through forecasting, monitoring, and controlling cash inflows and outflows, while arranging for deficits over the life of a business. Construction companies implement cash flow management strategies at both the organizational and project levels. Contractors must balance their cash outflow for workers, equipment, materials, etc., with the cash inflow from customer payments during project execution to ensure smooth project completion with minimal financing (Ning et al., 2017). Financial constraints can jeopardize project completion, with more than 60% of construction contractors' failures attributed to financial factors. Most construction organizations lack the liquidity to support their day-to-day operations, leading to potential project disruption or contractor bankruptcy (Lu et al., 2016).

Cash flow forecasting is a crucial element of cash flow management. Accurate forecasting allows contractors to anticipate potential shortfalls and plan accordingly to mitigate risks. This involves not only projecting revenues and expenses but also understanding the timing of these cash flows to ensure that sufficient funds are available to meet obligations as they arise. Traditional methods of cash flow forecasting often fall short in addressing the complexities and uncertainties inherent in construction projects, particularly when multiple projects are involved simultaneously.

Given these challenges in cash flow management, this study seeks to address these issues in a targeted manner. The objective of this study is to enhance the accuracy and reliability of cash flow forecasting in construction projects, with a focus on financial risk management in a multi project environment. Specifically, this research aims to (1) develop a predictive model that accounts for financial risk in construction projects, (2) integrate Value at Risk (VaR) and Monte Carlo simulation to enhance the forecasting process, and (3) provide a comprehensive framework for managing cash flow risk across multiple projects. Achieving these objectives will help construction companies reduce the risk of project failure due to poor financial management.

According to Jorion (1997), Value at Risk (VaR) is a financial measure widely used to estimate the potential loss in the value of an asset or portfolio over a defined period of time at a given confidence level. According to Metropolis and Ulam (1949), Monte Carlo simulation is a computational method well-established for modeling the likelihood of various outcomes based on random variables.

By integrating Value at Risk (VaR) into existing risk assessment frameworks, our research contributes to the theoretical landscape of construction cash flow management. Providing a more comprehensive understanding of how financial risk can be modelled and managed within construction project portfolios, this contribution enriches the academic discourse. This study delves into the practical applications of VaR in the construction industry, a concept predominantly utilized in the finance sector. By adapting financial risk management tools to the construction context, this research bridges a significant gap and offers innovative solutions to longstanding challenges in cash flow management.

This study aims to provide a comprehensive model for predicting the cash flow of construction projects and managing associated financial risks. Given the critical role of cash flow in projects and the intricate tie between a business's financial health and its cash flow, accurate forecasting is not merely important but vital for a company's survival. Proper cash flow management ensures that actual cash flow aligns with designated baselines, which is crucial for maintaining financial stability and fulfilling transactional commitments.

The Project Management Body of Knowledge, along with various tools and techniques in construction project management, generally focuses on achieving unit goals within a project. However, the contemporary landscape of project execution increasingly involves a multi project environment. Turner and Speiser (1992) suggest that most project activities occur within portfolios or programs, with Payne (1995) estimating that up to 90% of all projects are executed in multi-project settings. The simultaneous implementation of multiple projects presents unique challenges, such as handling projects in different sectors, dynamically changing project priorities, sharing resources, matching project costs with available budgets, and collecting detailed project information. Managing cash flow risk across multiple concurrent construction projects requires addressing these complexities to ensure financial stability and project success.

Projects are inherently exposed to various risks due to existing uncertainties, which significantly impact cash flow forecasting. These risks encompass changes in time, cost, scope of work, employer reliability, workforce injury, inflation, sanctions, and more. Each risk occurrence affects the project's cash flow differently, making risk identification and prediction essential for enhancing the accuracy of forecasts and outcomes. Value-at-Risk (VaR), a robust tool for risk quantification, measures the potential loss of financial assets by addressing the question, "How much could be lost at a given time?" VaR is crucial for understanding the maximum potential losses under normal market conditions over a specified period, with a given confidence level (95% in this study). It is essentially a metric that gauges the worst expected losses within a set time frame, ensuring a 95% certainty that losses will not exceed a specific value.

Several methods for calculating VaR include the variance-covariance method, historical data simulation, and Monte Carlo simulation. The Monte Carlo simulation method, in particular, employs computational algorithms to generate many random samples and simulate future changes, thus approximating possible outcomes accurately (Du and Li, 2008). By using simulation methods to analyze the statistical distribution of risks, this research provides a comprehensive way to predict the cash flow of construction projects in a multi-project environment while considering existing risks. This approach contributes to the understanding of cash flow dynamics and underscores the interaction between project execution and risk management, providing new insights into maintaining financial resilience in the construction industry.

This study on predicting cash flows of multiple construction projects using Value at Risk aims to improve project success rates and ensure the financial stability of construction companies by comparing actual cash flows with predetermined baselines. Key outputs include cash flow prediction models, Value at Risk analysis, financial stability indicators, and risk mitigation strategies—all designed to provide a comprehensive framework for managing financial uncertainty in construction projects.

The primary objective of this study is to enhance the robustness and reliability of cash flow predictions in construction projects by integrating VaR and simulation-based optimization. In addition to this primary objective, the research aims to bridge the gap between theory and practice in cash flow management, address the challenges and uncertainties of managing multiple construction projects, and develop a reliable forecasting method that assesses the impact of various risks to inform decision-making. This approach not only addresses the financial volatility and inherent risks in construction projects but also provides a strategic framework for effective financial planning and risk management. By aligning actual cash flows with designated baselines, this study aims to improve project success rates and ensure the financial stability of construction firms.

Moreover, this study delves into the practical applications of VaR in the construction industry, offering innovative solutions to longstanding challenges in cash flow management. The insights gained from this study are expected to contribute to the development of more resilient construction project management practices, which are essential in today's dynamic and often unpredictable economic environment.

The study's methodology involves a thorough review of existing literature, the development of a robust predictive model, and the application of this model to real-world case studies. This comprehensive approach ensures that the findings are grounded in both theory and practice, providing valuable insights for both academics and practitioners in the field of construction project management.

The rest of the paper is organized as follows. Section 2 reviews the existing literature. Section 3 presents the model and assumptions. Section 4 presents the methodology and formulas. In Section 5, a case study is presented, and the associated results are discussed. Finally, Section 6 concludes and discusses future research.

2. Contextual background

This paper is connected to several literature streams, including the following streams:

2.1 Fuzzy logic

The use of fuzzy logic in cash flow management has been extensively explored in the construction industry to handle uncertainties and provide more accurate financial forecasting. Boussabaine and Elhag (1999) introduced fuzzy average techniques in cash flow analysis by developing membership functions in cash flow and defining linguistic variables over several evaluation periods. Their approach allowed for a more nuanced understanding of cash flow fluctuations over time, offering a valuable tool for construction managers dealing with uncertain financial conditions.

Lam et al. (2001) further integrated fuzzy reasoning and fuzzy optimization techniques to find the optimal path for shared cash flow with minimal resource utilization. This integration provided a strategic approach to resource management, ensuring that cash flow is optimized even in the presence of uncertainties. The incorporation of fuzzy logic into resource allocation models marked a significant advancement in construction project management, allowing for more flexible and adaptive planning strategies.

Yao et al. (2006) introduced a fuzzy, random, and one-period cash management model aimed at providing financial decision-makers with deeper insights into real cash management problems. Their model incorporated randomness and fuzziness to better simulate the unpredictable nature of construction project cash flows. This approach helped in understanding the interplay between different financial variables and their impact on overall project stability.

Further contributions to the application of fuzzy logic in construction cash flow management have been made by researchers such as Tabei et al. (2019), Yu et al. (2017), Mohagheghi et al. (2017), Maravas and Pantouvakis (2012), and Cheng and Roy (2011). These studies have expanded on the initial concepts, incorporating variousfuzzy logic models to address specific challenges in construction project management. For instance, Tabei et al. (2019) focused on using fuzzy logic to predict cash flow under uncertain conditions, while Yu et al. (2017) explored the integration of fuzzy sets with other optimization techniques to enhance cash flow forecasting accuracy

2.2 Cash flow risk

Risk management in construction projects has been a critical area of research, with numerous studies focusing on identifying, analyzing, and mitigating risks to ensure project success. Kishore et al. (2011) developed a method that considers a portfolio's cash flow risk to predict the cash flow of a project portfolio for a contractor. Their approach provided a comprehensive framework for assessing and managing financial risks across multiple projects, highlighting the importance of portfolio-level analysis in construction risk management.

In their study, Ding et al. (2024) applied the takt time planning method to optimize the construction process, and a risk control framework was proposed using Value at Risk (VaR) and Conditional Value at Risk (CVaR) approaches to predict the project schedule and cost performance under various scenarios. A case study of a high-rise residential project was conducted, and the study showed that takt time planning could reduce project duration and labor costs, providing valuable insights for improving project performance, reducing costs, and ensuring a safer work environment.

Curto et al. (2022) presented a method for quantifying project cost contingency reserves using Monte Carlo simulation, which accounts for stochastic and epistemic uncertainties as well as random uncertainties that affect the total project cost. The proposed method was validated on a real-case construction project in Spain, and the results show that it provides more accurate and consistent contingency reserves, in line with the real uncertainties that affect the risks identified in construction projects.

Zayed and Liu (2014) analyzed cash flow statements and identified several major factors affecting cash flow success, such as project delays, payment duration, poor planning, and the financial position of the contractor. Their findings underscored the multifaceted nature of cash flow risks and the need for integrated risk management strategies that address both project specific and broader financial issues.

Numerous researchers, including Puspa et al. (2020), Shang et al. (2018) and Sharifi and Bagherpour (2016), have recognized the importance of using fuzzy set theory or probability theory to produce and analyze project cash flows, addressing the significant risks involved. These studies have demonstrated the efficacy of combining fuzzy logic with probabilistic models to better capture the uncertainties and risks inherent in construction projects.

Yunping et al. (2021) developed a cash flow expense forecasting model and examined its performance in 33 transportation projects from 2007 to 2020. Their research highlighted the dynamic nature of cash flow risks and the need for continuous monitoring and adjustment of forecasting models to ensure their accuracy and relevance. The model developed by Yunping et al. (2021) incorporated various risk factors and provided a robust framework for predicting cash flow in large-scale transportation projects.

Additionally, the study by Padmakumari and Shaik (2023) highlights the importance of accurate volatility estimation in market risk management. They compare traditional GARCH and TARCH models with range-based RGARCH and RTARCH models, demonstrating that the latter provides better predictive accuracy for Value at Risk (VaR) due to their ability to incorporate more information. This approach could be highly beneficial in the construction industry for improving financial risk management and enhancing the accuracy of risk forecasts.

Blyth and Kaka (2006) introduced a multiple linear regression model for forecasting S-curves, emphasizing the need for accurate individualized cash flow forecasting. Their model provides an alternative to traditional forecasting methods, contributing significantly to the field of construction finance.

Dabirian et al. (2023) analyzed the impact of financial policies on construction projects using system dynamics, which aligns with this study’s focus on simulation-based optimization techniques. Their findings underscore the importance of strategic financial planning in mitigating risks and enhancing cash flow stability.

2.3 Project time management

Time management is another critical aspect of construction project management, with numerous studies focusing on optimizing project schedules to minimize delays and ensure timely completion. Liu and Wang (2010) proposed a model for optimizing the cash flow of a portfolio, which can reduce financial pressure by adjusting work schedules without causing delays. Their model demonstrated how strategic adjustments to project timelines could enhance cash flow management and reduce the financial strain on contractors.

The literature identifies four main factors related to construction delays: payment delays, poor cash flow management, insufficient financial resources, and financial market instability

(e.g. Abdulrahman et al., 2009). These factors are interrelated, and addressing them requires a comprehensive approach that integrates financial planning, risk management, and project scheduling.
Sobieraj and Metelski (2022) introduce the combination of Monte Carlo simulation and the Time-at-Risk (TaR) approach, a method adopted from finance, to examine the risks of schedule delays in a more comprehensive way, taking into account the covariance matrix between project phases and the impact of phase rearrangement on the overall project schedule.

The increasing complexity and volatility of construction work, resources, and cash flows often result in time and cost overruns and, in the worst case, the failure of a project. The use of traditional methods in construction management has been challenged by the need to optimize resource flows in such a dynamic and uncertain environment. In their paper, Jiang et al. (2023) propose a model that utilizes a Partially Observable Markov Decision Process (POMDP) to address these challenges and introduces a Deep Reinforcement Learning (DRL) approach for adaptive, continuous control of labor and material flows to enhance both work and cash flow optimization.

Sambasivan and Soon (2007) identified ten critical causes of delay from a list of 28, categorizing six main effects of delay. The most significant factors include unstable financial records of the contractor, poor customer economic and financial management, difficulties in obtaining capital loans, and inflation. Their research provided a detailed analysis of the causes and effects of delays, offering valuable insights for developing effective mitigation strategies.

Given the importance of cash flow in projects and the impact of risks and uncertainties, accurate cash flow forecasting is crucial for the survival of businesses. This research quantifies the impact of identified risks on cash flow using VaR. VaR measures the maximum potential loss of financial assets, answering the question, “How much is the potential loss at a given time?” Several methods for calculating VaR include the variance-covariance method, simulation based on historical data, and Monte Carlo simulation. In this study, we use the simulation method to analyze the statistical distribution of risks, providing a novel approach to predicting the cash flow of construction projects in a multi-project environment.

2.4 Research gap and contributions

Despite significant research in construction risk analysis and management, notable gaps remain:

(1) Although several studies focus on risk analysis, there is a lack of research specifically addressing VaR and Cash Flow at Risk (CFaR) in construction projects, with these concepts mainly used in the finance industry.
(2) While numerous studies on construction risk management focus on single projects, there is a need for risk analysis in multiple projects, where integrating existing projects presents greater complexity.
(3) The application of CFaR in construction projects is notably sparse, highlighting the need for practical and managerial reports at the operational level.

This paper addresses these gaps by providing a comprehensive approach to predicting the cash flow of construction projects, considering multiple projects and associated risks, thereby fulfilling the requirements of the construction industry. By integrating VaR with simulation-based optimization, this study offers a novel framework for managing financial risks in construction projects, enhancing their financial stability and success rates.

3. Research methodology

This study adopts a pragmatic research philosophy, which emphasizes practical application and the use of methods that best address the research problem. Pragmatism is particularly suitable for research in construction cash flow management due to the industry's complex and dynamic nature, where real-world solutions are highly valued.

Guided by this philosophical approach, our methodology combines both quantitative and qualitative methods to develop a robust predictive model. The quantitative aspect involves mathematical modeling and simulation techniques to forecast cash flows and assess risks. The qualitative aspect incorporates expert judgment and industry insights to ensure that the model reflects practical realities and can be effectively applied in real-world scenarios.

The influence of pragmatism on our methodology is evident in the following ways:

1) Focus on Practical Outcomes: We aim to produce results that are not only theoretically sound but also practically useful for construction professionals managing cash flow across multiple projects.
2) Integration of Multiple Methods: By blending quantitative models with qualitative insights, we leverage the strengths of both approaches to address the research problem comprehensively.
3) Adaptability to Real-World Conditions: The model is designed to accommodate the unpredictable nature of construction projects, acknowledging that while not all variables can be controlled, effective management is possible through informed decision-making.

In line with the pragmatic paradigm, we make several key assumptions:

1) Reliance on Accurate Data: The model assumes that the data used for simulation is accurate and representative of real-world conditions. This is essential for producing reliable and actionable results.

2) Predictability of Risks Using Historical Data and Expert Judgment: This study assumes that risks can be forecasted using historical data and expert judgment, ensuring a realistic and data-driven risk assessment framework. While acknowledging that unforeseen external factors (such as sudden economic changes or new regulations) may impact cash flow, our model focuses on risks that can be reasonably predicted and managed within the project's scope.

While our model is designed to be robust and practical, we recognize certain limitations inherent in its application. The reliance on accurate and representative data means that any inaccuracies or biases in the input data could affect the reliability of the results. Data quality issues such as outdated information, measurement errors, or incomplete datasets may lead to less accurate forecasts. Additionally, although we assume that risks can be anticipated based on historical data and expert judgment, there is always an element of uncertainty in risk assessment. Unforeseen events or atypical circumstances—such as sudden economic downturns, regulatory changes, or unprecedented global events—may not be captured by historical trends or expert insights. These limitations suggest that while our model provides valuable insights, it should be used in conjunction with continuous monitoring of real-world developments and supplemented with qualitative assessments to ensure adaptability to changing conditions.

By adopting a pragmatic stance, we prioritize the development of a practical tool that can assist construction managers in effectively forecasting cash flows and managing financial risks. This philosophical foundation ensures that our research is grounded in real-world application, enhancing its relevance and utility in the field of construction project management.

To operationalize this methodology, we developed a detailed model incorporating these principles, formulated specific equations to calculate cash flows and risks, and applied the model to a real-world case study involving multiple construction projects. The following subsections provide a comprehensive overview of these components, detailing how we implemented our approach, and the insights gained from our analysis.

3.1 Model

In this section, we present the model and assumptions underlying our methodology for predicting the cash flow of construction projects in a multi-project environment. The model aims to incorporate various project-specific and overall financial factors to provide a comprehensive framework for cash flow forecasting and risk management. The following key assumptions are considered:

3.1.1 Multiple projects. Our model simultaneously considers three construction projects. Each project has a distinct Work Breakdown Structure (WBS), which includes detailed information about the project's time, cost, and required resources. The WBS allows us to capture the unique characteristics and requirements of each project while analyzing their collective impact on cash flow and risk management. This multi-project perspective is crucial as it reflects the real-world scenario where construction companies often manage multiple projects concurrently, each with its own set of challenges and timelines.

3.1.2 Progressive payment structure. The payment type for the projects is in the form of progressive works, commonly known as advance payment. This means that payments are made in installments based on the completion of specific project milestones or progress stages. The advanced payment for each project is calculated using the project's price and the working progress percentage, as detailed in the results section. This payment structure is critical for managing cash flow effectively, as it aligns incoming funds with project progress, thereby reducing the financial strain on contractors.

3.1.3 Assignment to second-hand contractors. It is assumed that up to two activities per project can be assigned to subcontractors. This flexibility allows project managers to outsource specific tasks when necessary, helping to manage workload and resources more effectively. The model accounts for these assignments and their impact on overall project costs and timelines. Subcontracting can be a strategic decision to enhance efficiency, meet deadlines, and manage specialized tasks that require specific expertise or equipment.

3.1.4 Predictability of risks. The model assumes that risks are predictable to some extent. This predictability allows for the identification, classification, and assessment of potential risks that each project may face. By understanding these risks in advance, we can estimate their impact on project cash flow and take proactive measures to mitigate them. The simulation methods used in the methodology, including VaR and Monte Carlo simulation, help quantify these risks and their potential effects. This approach provides a structured way to incorporate risk management into cash flow forecasting, ensuring that potential financial disruptions are accounted for and managed proactively.

3.1.5 Model structure. The model integrates the above assumptions into a cohesive framework for analyzing cash flow and risk management across multiple projects. Key components of the model include:

1) Work Breakdown Structure (WBS): A detailed breakdown of tasks, resources, and timelines for each project. The WBS serves as the foundation for scheduling, budgeting, and resource allocation, providing a clear roadmap for project execution.
2) Progressive Payment Calculations: Estimation of advance payments based on project progress. This involves calculating the amount due at various project milestones, ensuring that cash inflows are aligned with the completion of significant project phases.
3) Risk Identification and Classification: Systematic identification and categorization of potential risks for each project. Risks are classified based on their nature (e.g. financial, operational, technical) and their potential impact on project outcomes. This classification helps prioritize risk management efforts and allocate resources effectively.
4) Cash Flow Calculations: Computation of cash inflows and outflows, considering both project-specific and overall financial performance. This includes estimating the costs associated with labor, materials, equipment, and other project-related expenses, as well as forecasting revenue based on project milestones and payment schedules.
5) Simulation and Analysis: Use of simulation techniques to analyze the impact of risks and validate cash flow predictions. This involves running multiple scenarios to assess the robustness of the cash flow forecasts and identify potential vulnerabilities. The simulation results provide insights into the likelihood of various outcomes and help develop contingency plans to address potential financial shortfalls.

By incorporating these assumptions, the model provides a comprehensive tool for managing and forecasting the cash flow of construction projects, ensuring that financial risks are effectively identified, quantified, and mitigated. This approach supports the successful completion of projects within budget and on schedule while also enhancing the overall financial stability of construction firms. The model's flexibility allows it to be adapted to different project sizes and types, making it a valuable asset for construction managers in diverse contexts.

3.2 Formulas

In this section, we outline the detailed steps and equations used to calculate the cash flow for multiple projects, taking into account the impact of various risks. The methodology is divided into several stages, from initial calculations of cash flow to risk analysis and management, ensuring a comprehensive approach to financial planning in construction projects.

3.2.1 Cash flow calculation. To determine the effects of risks on a project's cash flow, we first calculate each project's cash flow. In these calculations, i is an indicator of project number. This process involves several key equations:

(1) Calculating advanced payment: Each project has an income. This income is called the advanced payment (***AP_i***). This is calculated using Equation (1). In this equation, Vi represents the price of project i and ***WP_i*** shows how much of the project i is completed (the working progress percentage).

$$AP_i = V_i \times WP_i \tag{1}$$

(2) Calculating total cost without risk: The total cost without considering risks is calculated using Equation (2). In this equation, ***CH_i*** is the total cost of project i without risk.

$$CH = \sum_{i=1}^{3} CH_i \tag{2}$$

(3) Calculating project cash flow: The cash flow for each project (***CF_i***) is then calculated using Equation (3).

$$CF_i = AP_i - CH_i \tag{3}$$

(4) Calculating total cash flow: The total cash flow (CF) is calculated by adding up the cash flows from all projects as follows.

$$CF = \sum_{i=1}^{3} CF_i \tag{4}$$

(5) Calculating total risk cost: Finally, the total risk cost is calculated using Equation (5). In this equation, ***CR_i*** is the excess cost for project i due to risks.

$$CR = \sum_{i=1}^{3} CR_i \tag{5}$$

3.2.2 Value at risk (VaR). VaR is a key metric used to quantify financial risk. The VaR computational formula is defined as:

$$\int_{-\infty}^{VaR} f(x)dx = 1 - a = 0.05 \tag{6}$$

In this equation:

(1) f(x) represents the probability density function of the distribution of returns.
(2) A is the confidence level, which is 95% in this study.

3.2.3 Simulation for normal distribution. To simulate a normal distribution, we follow these steps:

(1) Generate random numbers: 12 random numbers are generated using Excel and the RAND formula.

(2) Calculate the Value of Z: Sum the 12 random numbers ($\boldsymbol{R_i}$) and subtract 6:

$$Z = \sum_{i=1}^{12} R_i - 6 \tag{7}$$

(3) Mean ($\boldsymbol{\mu}$): Find the mean by averaging the minimum (MIN) and maximum (MAX) values:

$$\mu = \frac{MIN + MAX}{2} \tag{8}$$

(4) Calculate the standard deviation ($\boldsymbol{\sigma}$): Determine the standard deviation suing:

$$\sigma = \sqrt{MAX - \mu} \tag{9}$$

(5) Calculate X value: The value of X is calculated by using:

$$X = Z \times \sigma + \mu \tag{10}$$

where X represents the value drawn from the normal distribution based on the calculated Z, mean (μ), and standard deviation (σ).

3.2.4 Forecast horizon and project planning. Determining the forecast horizon is crucial as each project is at a different stage of its lifecycle. The shorter the forecast horizon, the higher the certainty. The Work Breakdown Structure (WBS) of every project is recognized, and human and consumption resources for every task are defined. Additionally, the required equipment and estimations of time and costs for each task are identified. This detailed planning ensures that all aspects of the projects are considered in the cash flow calculations, providing a more accurate forecast.

3.2.5 Risk Identification and Classification. After defining the initial project information, we identify the risks for each project. These risks are classified and their potential impacts assessed. This step involves identifying and collecting relevant data to evaluate the risk. The classification of risks into categories (e.g. financial, operational, technical) helps in systematically addressing them and prioritizing risk management efforts.

3.2.6 Cash flow analysis and simulation. Following the cash flow analysis, the next step is to run simulations to analyze the results carefully. This simulation helps forecast potential outcomes and assess the impact of identified risks on project cash flow. The Monte Carlo simulation method is particularly useful in this context, as it allows for the analysis of multiple scenarios and the assessment of the likelihood of different outcomes.

3.2.7 Risk management and cash flow at risk. If the simulation results are deemed unacceptable, immediate actions are taken to mitigate risks using various risk management tools. If the results are acceptable, we determine the cash flow at risk and conduct a thorough analysis of these results, emphasizing the importance of these actions in effective project management. This involves re-evaluating the project plans and adjusting them as necessary to ensure that risks are minimized and the projects remain on track.

By following these steps, we ensure a comprehensive approach to managing and forecasting the cash flow of construction projects, considering multiple projects and associated risks. This methodology provides a robust framework for evaluating and mitigating financial risks in the construction industry. The detailed steps and equations outlined in this section form the backbone of our predictive model, ensuring that all relevant factors are accounted for in the cash flow forecasts. This structured approach not only enhances the accuracy of the predictions but also provides valuable insights for decision-making and strategic planning in construction project management (Figure 1).

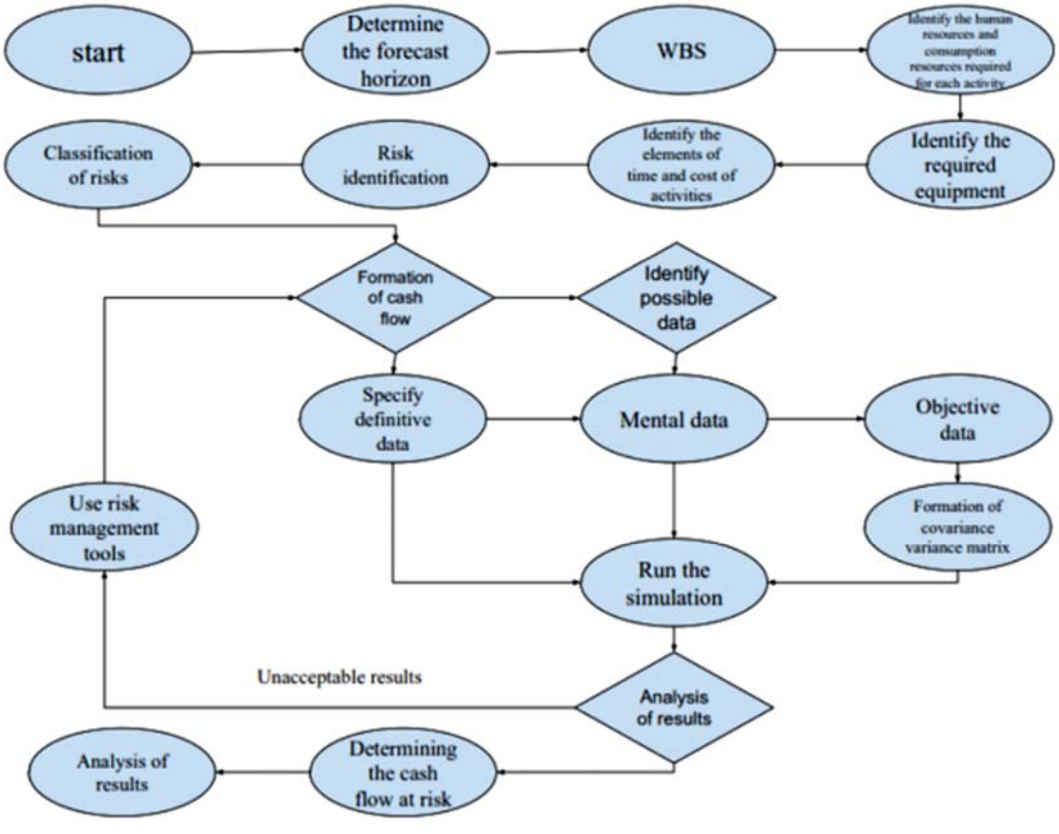


Figure 1. Solution methodology. Source: Authors' own work

3.3 Case study

To illustrate the practical application of our model, we conducted a case study involving three construction projects: the construction of a hospital, a building, and a school, denoted by **P_1,** **P_2,** and **P_3**, respectively.

Based on the identified resources, we begin by computing the cash flow of each project without considering risks. Following this, we identify the risks for each project using historical data and expert knowledge. These risks are then classified into different categories, and a Risk Breakdown Structure (RBS) is created. To analyze these risks and their impacts, we assign a probability of occurrence and severity to each risk and prioritize the risks for corrective actions. This helps us identify significant risks that demand immediate attention. Subsequently, we employ Monte Carlo simulation and Excel to quantitatively analyze these risks, including obtaining the probability distribution of each risk.

The following sections detail the different steps explained above.

4. Results

4.1 Computing cash flow without considering risks

4.1.1 Project details. Each of the three projects was planned with a distinct Work Breakdown Structure (WBS), detailing the tasks, resources, and timelines necessary for their completion. The projects began simultaneously on October 22, 2020, with estimated completion dates by February 17, 2022. The WBS for each project included specific milestones such as foundation work, structural work, roofing, and interior finishes, among others. Each project had unique resource requirements, including labor, materials, and equipment, which were carefully documented and accounted for in the cash flow calculations. The price of each project was as follows (Vi is a parametere that obtained from the employer):

(1) The price of hospital construction project (**V_1**): $193,349.115
(2) The price of building construction project (**V_2**): $163,058.717
(3) The price of school construction project (**V_3**): $42216.919

Note that the above prices are converted from Toman (the Iranian currency) to US Dollars.

4.1.2 Progress and advanced payment calculations. As of October 26, 2021, the progress of each project and the total cost without risk up to that date, based on the WBS, were as follows (these amounts are calculated according to the WBS of each project and data from the employer):

(1) For hospital construction project (**P_1**):
- **WP_i** = 71%
- CH_i = $57,932.490

(2) For building construction project (**P_2**):
- **WP_2** = 72%
- **CH_2** = $50,035.416

(3) For school construction project (P_3):

- WP_3 = 73%
- CH_3 = $19,443.591

Consequently, the advanced payments and cash flows were calculated using Equation (1) and Equation (3), respectively, as follows:

(1) ***AP*1** = 0.71 * $193349.115 = $137277.872
(2) AP_2 = 0.72 * $163059.717 = $117402.276
(3) AP_3 = 0.73 * $42216.919 = $30818.351
(4) CF_1 = $137277.872 – $57932.490 = $79345.382
(5) CF_2 = $117402.276 – $50035.416 = $67366.861
(6) CF_3 = $30818.351 – $19,443.591 = $11374.760

These calculations are summarized in Table 1.

4.2 Risk identification, classification, and prioritization

For each project, we identified potential risks according to Table 2. The risk IDs are according to the RBS. The risk assessment process involved consultation with project managers, analysis of historical data, and expert judgment. Risks were categorized into financial, operational, technical, and external risks. Key risks identified included delays due to weather, supply chain disruptions, labor shortages, cost overruns, and regulatory changes. In Table 2, each risk is associated with a probability of occurrence and a severity impact, which are obtained from historical data and expert opinion. The probabilities in Table 2 are classified into five groups: very low (VL), low (L), average (M), high (H), and very high (VH), based on the trade-offs shown in Table 3.

Table 1. Information about each project

i	P_i	Start date	Finish date	V_i	WP_i	AP_i	CH_i according to WP_i	CF_i	CF
1	constructing a hospital	2020/10/22	2022/02/17	193349.115	71%	137277.872	57932.490	79345.382	158087.003
2	constructing a building	2020/10/22	2022/02/17	163058.717	72%	117402.276	50035.416	67366.861	
3	constructing a school	2020/10/22	2022/02/17	42216.919	73%	30818.351	19443.591	11374.760	

Source(s): Authors' own work

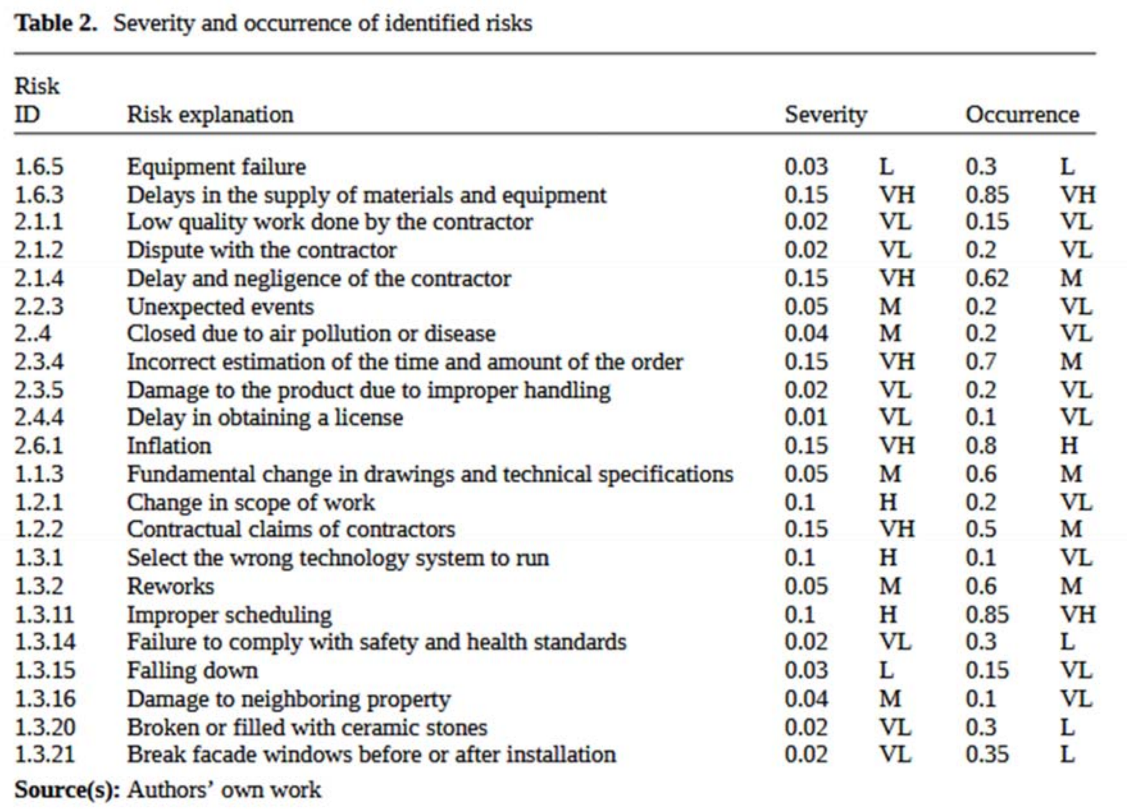


Table 2. Severity and occurrence of identified risks

Risk ID	Risk explanation	Severity		Occurrence	
1.6.5	Equipment failure	0.03	L	0.3	L
1.6.3	Delays in the supply of materials and equipment	0.15	VH	0.85	VH
2.1.1	Low quality work done by the contractor	0.02	VL	0.15	VL
2.1.2	Dispute with the contractor	0.02	VL	0.2	VL
2.1.4	Delay and negligence of the contractor	0.15	VH	0.62	M
2.2.3	Unexpected events	0.05	M	0.2	VL
2..4	Closed due to air pollution or disease	0.04	M	0.2	VL
2.3.4	Incorrect estimation of the time and amount of the order	0.15	VH	0.7	M
2.3.5	Damage to the product due to improper handling	0.02	VL	0.2	VL
2.4.4	Delay in obtaining a license	0.01	VL	0.1	VL
2.6.1	Inflation	0.15	VH	0.8	H
1.1.3	Fundamental change in drawings and technical specifications	0.05	M	0.6	M
1.2.1	Change in scope of work	0.1	H	0.2	VL
1.2.2	Contractual claims of contractors	0.15	VH	0.5	M
1.3.1	Select the wrong technology system to run	0.1	H	0.1	VL
1.3.2	Reworks	0.05	M	0.6	M
1.3.11	Improper scheduling	0.1	H	0.85	VH
1.3.14	Failure to comply with safety and health standards	0.02	VL	0.3	L
1.3.15	Falling down	0.03	L	0.15	VL
1.3.16	Damage to neighboring property	0.04	M	0.1	VL
1.3.20	Broken or filled with ceramic stones	0.02	VL	0.3	L
1.3.21	Break facade windows before or after installation	0.02	VL	0.35	L

Source(s): Authors' own work

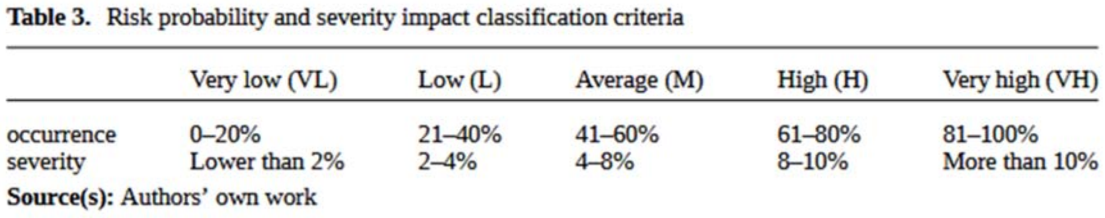


Table 3. Risk probability and severity impact classification criteria

	Very low (VL)	Low (L)	Average (M)	High (H)	Very high (VH)
occurrence	0–20%	21–40%	41–60%	61–80%	81–100%
severity	Lower than 2%	2–4%	4–8%	8–10%	More than 10%

Source(s): Authors' own work

Table 4 Prioritizes the identified risks of Table 2 by using a Strengths-Opportunities (SO) matrix. The SO matrix helps us identify six significant risks from the twenty-two identified, which demand immediate attention, as shown in Table 5.

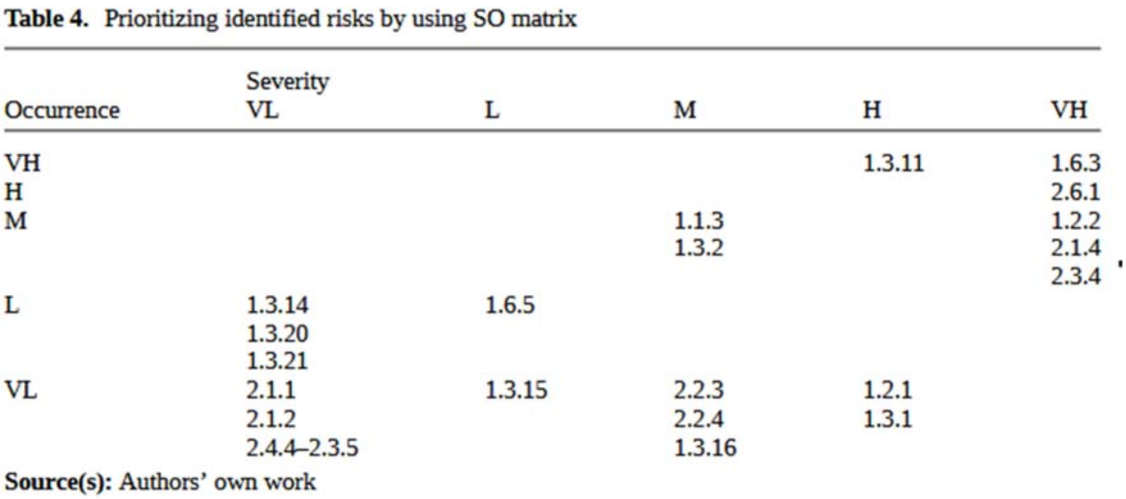


Table 4. Prioritizing identified risks by using SO matrix

	Severity				
Occurrence	VL	L	M	H	VH
VH				1.3.11	1.6.3
H					2.6.1
M			1.1.3 1.3.2		1.2.2 2.1.4 2.3.4
L	1.3.14 1.3.20 1.3.21	1.6.5			
VL	2.1.1 2.1.2 2.4.4–2.3.5	1.3.15	2.2.3 2.2.4 1.3.16	1.2.1 1.3.1	

Source(s): Authors' own work

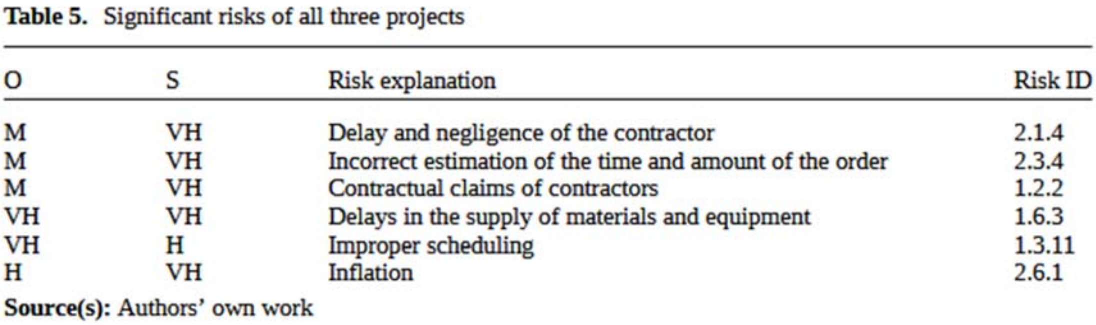


Table 5. Significant risks of all three projects

O	S	Risk explanation	Risk ID
M	VH	Delay and negligence of the contractor	2.1.4
M	VH	Incorrect estimation of the time and amount of the order	2.3.4
M	VH	Contractual claims of contractors	1.2.2
VH	VH	Delays in the supply of materials and equipment	1.6.3
VH	H	Improper scheduling	1.3.11
H	VH	Inflation	2.6.1

Source(s): Authors' own work

4.3 Simulation and value at risk (VaR)

To quantify the impact of identified risks on project cash flows, we utilized the Monte Carlo simulation method. This approach involved generating random samples to simulate possible future outcomes based on the probability distributions of the identified risks. The VaR was calculated to measure the maximum potential loss with a 95% confidence level using Equation (6).

The simulation results provided a distribution of possible cash flows, from which we derived the VaR. The cash flow at risk was determined by identifying the cash flow amount with a 5% probability of being lower than the estimated value. The distributions and information about these risks are presented in Table 6. In this table, the effective cost is the total cost (CH), which is calculated as the sum of $\boldsymbol{CH_i}$ for each project. Limit percentages are obtained from expert opinions, and the upper and lower limits are calculated by multiplying the effective cost by the limit percentage for each risk.

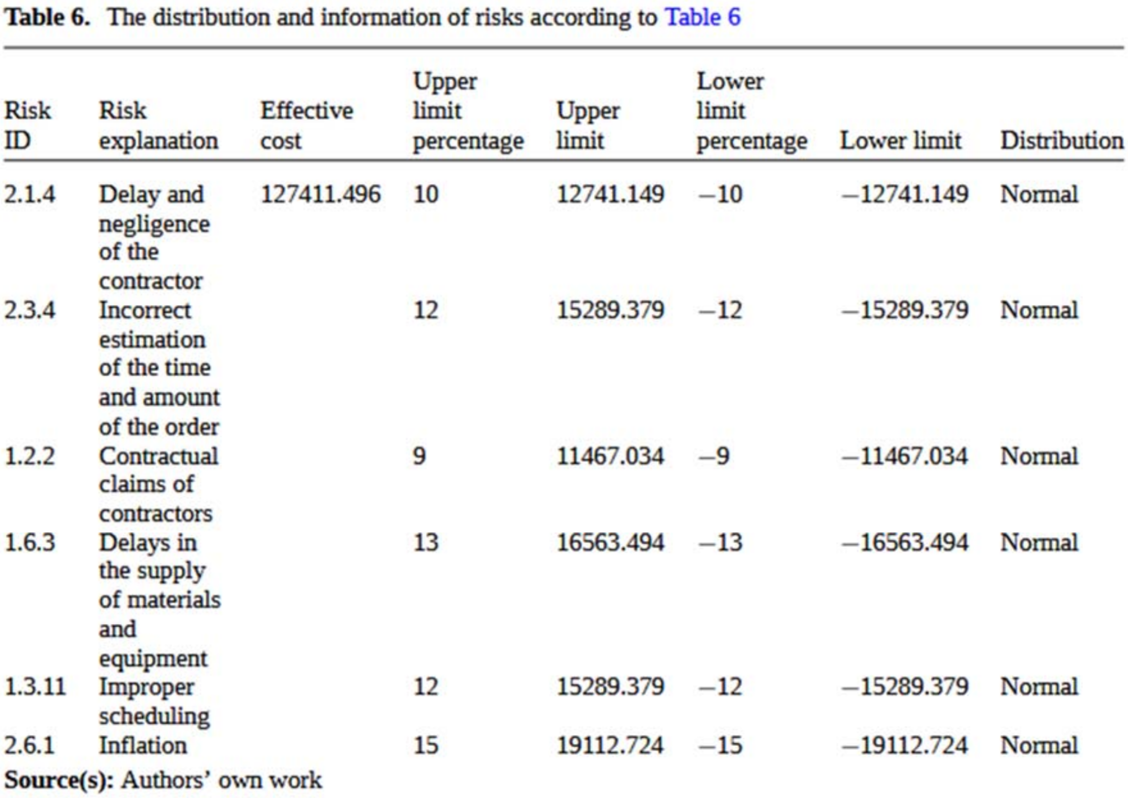


Table 6. The distribution and information of risks according to Table 6

Risk ID	Risk explanation	Effective cost	Upper limit percentage	Upper limit	Lower limit percentage	Lower limit	Distribution
2.1.4	Delay and negligence of the contractor	127411.496	10	12741.149	−10	−12741.149	Normal
2.3.4	Incorrect estimation of the time and amount of the order		12	15289.379	−12	−15289.379	Normal
1.2.2	Contractual claims of contractors		9	11467.034	−9	−11467.034	Normal
1.6.3	Delays in the supply of materials and equipment		13	16563.494	−13	−16563.494	Normal
1.3.11	Improper scheduling		12	15289.379	−12	−15289.379	Normal
2.6.1	Inflation		15	19112.724	−15	−19112.724	Normal

Source(s): Authors' own work

The summary of cash flow results from the simulation is shown in Table 7. In this table, the cost before simulation (CH) is calculated as the sum of ***CH_i*** for each project. The amount of cost increase after simulation is obtained through the steps provided in the "simulation for normal distribution" section. The cost after simulation is the result of the sum of the cost before simulation (CH) and the amount of cost increase after simulation.

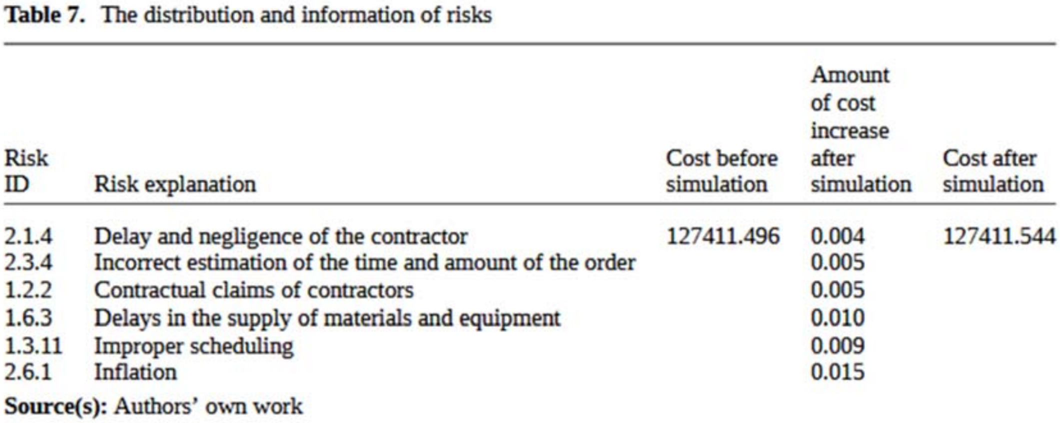


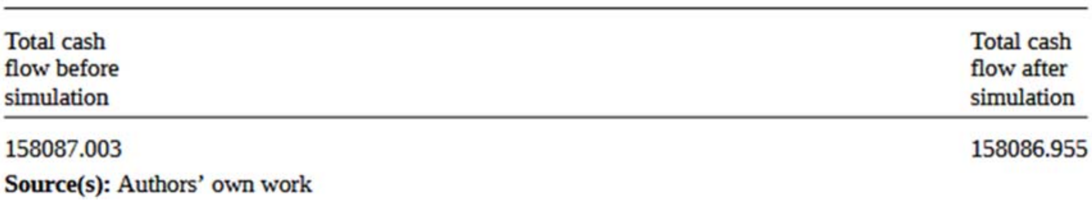
Table 7. The distribution and information of risks

Risk ID	Risk explanation	Cost before simulation	Amount of cost increase after simulation	Cost after simulation
2.1.4	Delay and negligence of the contractor	127411.496	0.004	127411.544
2.3.4	Incorrect estimation of the time and amount of the order		0.005	
1.2.2	Contractual claims of contractors		0.005	
1.6.3	Delays in the supply of materials and equipment		0.010	
1.3.11	Improper scheduling		0.009	
2.6.1	Inflation		0.015	

Source(s): Authors' own work

The simulation results revealed significant insights into the potential financial outcomes of the projects under different risk scenarios. The average cash flow and the cash flow with a 5% probability were calculated, both considering the effect of identified risks on the cost, allowing us to determine the cash flow at risk. The results are shown in Table 8.

Table 8. Cash flow before and after simulation



Total cash flow before simulation	Total cash flow after simulation
158087.003	158086.955

Source(s): Authors' own work

To demonstrate the precise calculation of risky cash flow, we consider the detailed figures (the cash flow with a probability of 5% and the average cash flow are calculated using the Excel file). For the combined projects:

$$\text{cash flow with 5\% probability} - \text{average cash flow} = \text{risky cash flow}$$

$$158091.943 - 158086.958 = 4.986$$

The analysis showed that each project had specific financial vulnerabilities, with the hospital construction project having the highest cash flow at risk. This was primarily due to its larger scale and more complex risk profile. The total cash flow at risk for all projects was calculated by summing the individual cash flows at risk:

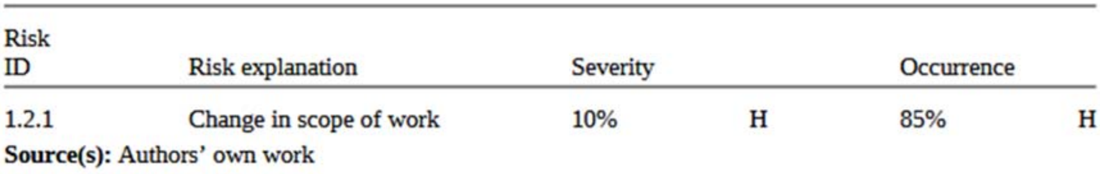
$$\text{Total Cash Flow at Risk} = -\$50,000 + -\$100,000 + -\$200,000 = -\$350,000$$

The total cash flow before simulation is obtained from Table 2, and the total cash flow after simulation is calculated by subtracting the cost of risks (as shown in Table 7) from the total cash flow before simulation.

4.4 Sensitivity analysis

In this part, we use sensitivity analysis to analyze how sensitive the values of the independent variables (inputs of the system) are. For this purpose, we assume that the occurrence of four of the insignificant risks is increased. For example, the occurrence of the risk of "Change in scope of work", "Major changes in drawings and technical specifications", Poor quality of work done by the contractor", and "Equipment failure" are increased to 85%, 80%, 75% and 80%, respectively, due to external factors. As a result, this risk becomes significant. In Table 9, we calculate the effects of this risk on the cash flow of the project.

Table 9. Severity and occurrence of the risk "Change in scope of work"

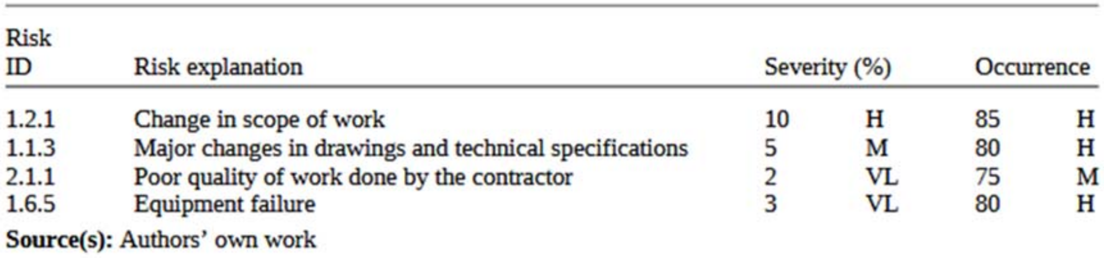


Risk ID	Risk explanation	Severity		Occurrence	
1.2.1	Change in scope of work	10%	H	85%	H

Source(s): Authors' own work

Table 10 provides the distribution and information for the "Change in scope of work", "Major changes in drawings and technical specifications", Poor quality of work done by the contractor", and "Equipment failure" risks. According to Table 10, the effective cost is calculated as the sum of CHi for each project. Limit percentages are obtained from expert opinions, and the upper and lower limits are calculated by multiplying the effective cost by the limit percentage for each risk.

Table 10. Severity and occurrence of four risks

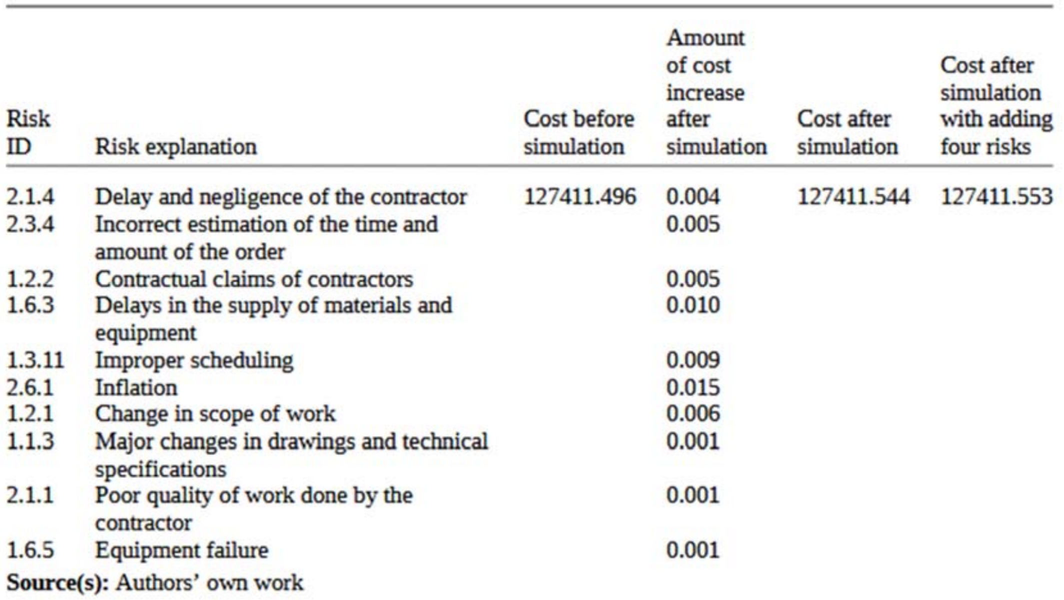


Risk ID	Risk explanation	Severity (%)		Occurrence	
1.2.1	Change in scope of work	10	H	85	H
1.1.3	Major changes in drawings and technical specifications	5	M	80	H
2.1.1	Poor quality of work done by the contractor	2	VL	75	M
1.6.5	Equipment failure	3	VL	80	H

Source(s): Authors' own work

Table 11 presents the simulation results for each risk, considering the “Change in scope of work”, “Major changes in drawings and technical specifications”, Poor quality of work done by the contractor”, and “Equipment failure” risks. According to Table 11 and Figure 2, the cost after simulation is obtained from Table 8, and the cost after simulation with four risks is calculated by adding the amount of cost for each of the four risks, which are 0.006, 0.001, 0.001, 0.001, respectively, to the cost after simulation.

Table 11. The results of the simulation on each risk by considering four risks



Risk ID	Risk explanation	Cost before simulation	Amount of cost increase after simulation	Cost after simulation	Cost after simulation with adding four risks
2.1.4	Delay and negligence of the contractor	127411.496	0.004	127411.544	127411.553
2.3.4	Incorrect estimation of the time and amount of the order		0.005		
1.2.2	Contractual claims of contractors		0.005		
1.6.3	Delays in the supply of materials and equipment		0.010		
1.3.11	Improper scheduling		0.009		
2.6.1	Inflation		0.015		
1.2.1	Change in scope of work		0.006		
1.1.3	Major changes in drawings and technical specifications		0.001		
2.1.1	Poor quality of work done by the contractor		0.001		
1.6.5	Equipment failure		0.001		

Source(s): Authors' own work

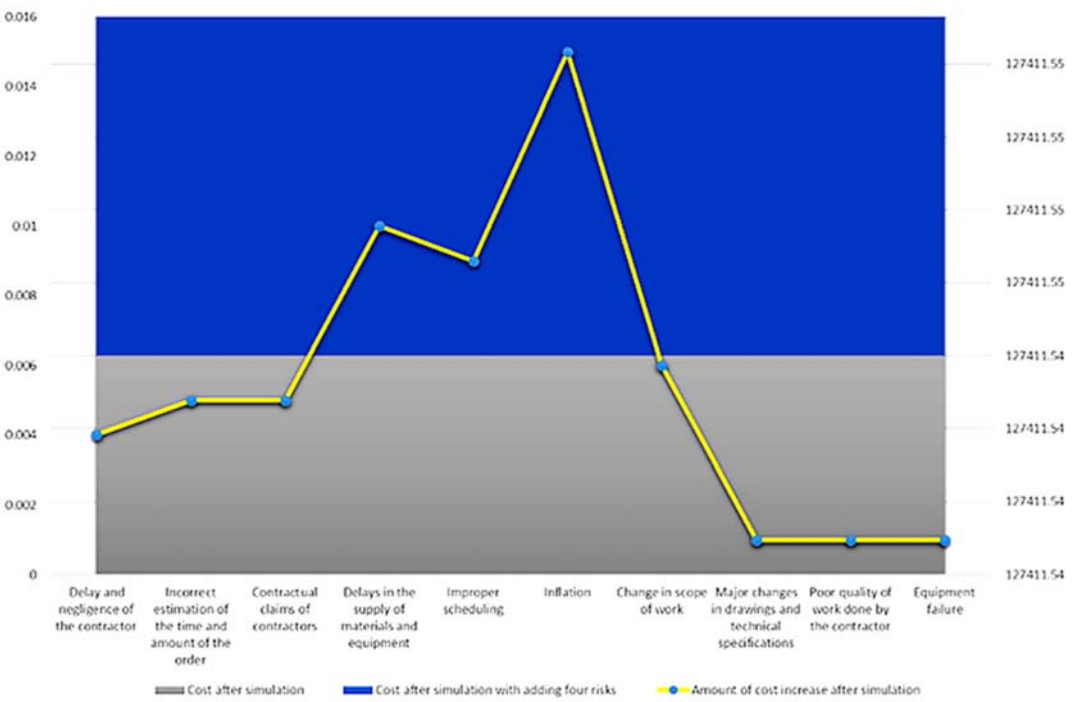


Figure 2. The results of the simulation on each risk by considering four risks. Source: Authors' own work

The detailed risk analysis and impacts after considering four risks are summarized in Table 12. Total cash flow before and after simulation is obtained from Table 2, and the total cash flow after simulation with four risks is calculated by subtracting the cost of the risk (according to Table 11) from the total cash flow after simulation. As previously mentioned, the cash flow with a probability of 5% and the average cash flow are calculated using the Excel file.

$$\text{Cash flow with 5\% probability} - \text{average cash flow} = \text{risky cash flow}$$
$$= 158093.0634 - (158086.9516) = 6.111.$$

Therefore, we are 95% sure that the loss will be at most 6.111. As a result, if we have more significant risks, the loss will be greater, and the total cash flow will be less.

Table 12. Cash flow before and after simulation, and by considering four risks in cash flow

Total cash flow before simulation	Total cash flow after simulation	Total cash flow after simulation with four risks
158087.003	158086.955	158086.946

Source(s): Authors' own work

5. Discussion

5.1 Comparative study

Compared to previous studies, particularly those focusing on the application of fuzzy logic such as Lam et al. (2001) and Yao et al. (2006), our study introduces significant advancements in the accuracy and robustness of cash flow forecasts by incorporating Value at Risk (VaR). Unlike earlier models, which lacked a robust mechanism for assessing the cumulative impact of risks across multiple projects, our method offers a probabilistic approach to understanding financial losses with a specified confidence level, thereby enhancing accuracy and robustness in decision-making.

By integrating VaR, our study provides a more systematic approach to quantifying risks in multiple construction projects, contributing to a deeper understanding of cash flow dynamics under uncertainty. Additionally, while previous models emphasized the analysis of a single project, our framework allows for simultaneous consideration of cash flows across multiple projects, helping managers develop more effective and comprehensive risk mitigation strategies.

In contrast to the study by Bai et al. (2024), who integrated system dynamics with an optimization sub-model to simulate risk interactions and devise risk response strategies, focusing primarily on resource allocation and dynamic project interactions, our proposed model differentiates itself by focusing specifically on financial health and proactive cash flow management through the integration of VaR. While Bai et al.'s work provides valuable insights into resource management under risk, our model quantifies financial risks affecting cash flow, providing a more precise estimation of potential losses—critical for ensuring liquidity and financial stability in construction firms.

Ronyastra et al. (2024) combined traditional feasibility study methods with Monte Carlo simulation to create a financial model assessing the likelihood of project payback and achieving positive Net Present Value (NPV), focusing on project viability from an investment perspective. In contrast, our study aims to enhance financial planning and risk management practices by integrating a cash flow forecasting framework with simulation-based optimization techniques. By incorporating VaR into our model, we provide a probabilistic assessment of potential financial risks over the project's duration, enabling construction managers to proactively manage cash flow uncertainties rather than solely evaluating project feasibility.

A comparison of our study with that of Savvides (2024) shows that both studies focus on the importance of financial modeling and risk management. Savvides (2024) focuses on creating a robust framework for utilizing Monte Carlo simulations in financial analysis, incorporating growth patterns for key risk variables to develop realistic and consistent scenarios. While their approach enhances scenario planning in financial analysis, our study goes a step further by specifically targeting cash flow management within construction project management. By integrating VaR, we enhance financial stability by quantifying the maximum potential loss over a specified time frame, allowing construction firms to prepare for adverse financial scenarios and maintain sufficient liquidity.

Rompotis (2024) examines the relationship between Greek firm performance, risk, and cash flow management, using panel data analysis to assess how various cash flow measures impact financial performance and stock returns. While their study provides empirical insights into the financial implications of cash flow management at a macro level, our research offers a practical framework for construction firms to proactively manage cash flow risks at the project level. By integrating VaR, we provide a proactive risk management approach, enhancing the financial resilience of firms by addressing the specific challenges they face at the project level.

Furthermore, previous studies, such as those by Lam et al. (2001) and Yao et al. (2006), emphasized the use of fuzzy optimization but lacked a rigorous method for assessing the cumulative impact of risks, particularly in multi-project environments. Our research fills this gap by employing a simulation-based technique, integrating VaR and Monte Carlo simulation, to estimate potential financial outcomes under different risk scenarios. This approach allows for a probabilistic assessment of cumulative risks, providing a more comprehensive understanding of financial uncertainties across multiple projects.

By reviewing previous studies, while Barraza et al. (2004) explored the use of random S-curves for probabilistic monitoring, our research advances this concept by integrating a quantitative risk assessment approach using VaR that directly informs cash flow predictions. By quantifying the potential financial losses associated with identified risks, our model allows for a more dynamic assessment of project performance over time. This enables managers to see how cash flow interacts with risk factors, enhancing their ability to make informed decisions and adjust strategies proactively.

Traditional forecasting methods for construction project cash flow management, such as linear regression and expert judgment, are based on historical data and prescriptive assumptions, producing point estimates that often ignore uncertainty. These methods assume predictable and stable patterns in project variables, but they do not account for the inherent variability in the cost of materials, availability of labor, and conditions in the marketplace—factors that are critical to multi-project management. As a result, they can lead to excessively optimistic or pessimistic forecasts that fail to account for accumulated risks or interactions among simultaneous projects.

In comparison, the simulation-based VaR model provides a more advanced approach by integrating Value at Risk (VaR) with Monte Carlo simulations to incorporate uncertainty in a dynamic and probabilistic way. This model offers a range of possible outcomes that reflect a variety of risks, such as fluctuating costs and schedule changes, rather than a single estimate. It also accounts for the cumulative risks of managing multiple projects, providing a comprehensive view of how risks interact across projects, thereby improving financial resilience and enabling more informed decision-making across construction project portfolios.

Overall, our methodology offers significant advancements over traditional methods by providing a comprehensive, probabilistic approach to cash flow risk management in multi-project construction environments. The integration of VaR and Monte Carlo allows for a moregranular, realistic, and dynamic assessment of risk, directly enhancing financial decision making in the construction sector. The model not only contributes to the academic literature, but also has a commercial impact, helping construction companies better manage their financial risks, improve their decision making, and enhance competitiveness and resilience in a volatile market.

5.2 Contributions to theory

The theoretical foundation of this study is based on Value at Risk (VaR), a financial risk management technique widely used in the finance industry.Although project management addresses various risks associated with project implementation, VaR's application to construction project management has not been fully explored. This study bridges this gap by introducing VaR into the construction sector. While VaR is well-established in finance, its adoption in construction project management remains limited. Despite the widespread use of risk management techniques in construction, the Project Management Body of Knowledge (PMBOK) does not yet include VaR in its quantitative risk management framework. Therefore, this research proposes VaR as a new tool in the Risk Management section of PMBOK, equipping project managers with a robust method to quantify financial and operational risks across multiple projects.

This study makes a significant theoretical contribution by integrating Value at Risk (VaR) into construction project cash flow forecasting models—a methodological innovation not previously applied in this context. The application of VaR addresses a gap in the literature, where existing research lacks a probabilistic approach to quantifying financial risks specifically for construction project portfolios. This study introduces a novel method for assessing potential financial losses with a specified confidence level. By integrating VaR, this research advances theoretical knowledge on anticipating and managing financial risks, offering a more robust model for understanding and mitigating financial uncertainty in construction projects.

A key objective of the study is to improve the accuracy and reliability of cash flow forecasts for construction projects. By integrating VaR, this research introduces a novel methodological perspective, demonstrating the critical role of probabilistic risk assessment in cash flow management, particularly in multi-project environments. By quantifying potential financial losses at a specific confidence level, this study extends existing theories on liquidity management, risk quantification, and project success in the construction industry. Furthermore, it provides deeper insights into the dynamics of cash flow, emphasizing how advanced risk quantification methods enhance financial decision-making.

In addition, this study filled a considerable gap in the existing literature by adapting financial risk management techniques, specifically VaR, to the construction industry. Previous research has not sufficiently explored the application of financial risk quantification methods within the context of construction project management. By emphasizing the interaction between project execution, risk, and cash flow management, our study presents a new perspective on managing financial risk in construction and offers practical applicability to the field. By bridging financial theory and construction practice, we contribute theoretically by demonstrating how construction firms can utilize advanced financial risk management tools to achieve greater financial stability and enhance project success amidst industry-specific risks.

Moreover, the study emphasizes the critical link between risk management and project success in the construction management literature. It provides deeper insights into the interplay between cash flow, financial risk, and project outcomes, demonstrating how advanced risk management techniques can enhance decision making and mitigate financial volatility in construction firms.

5.3 Practical implications

This study examines the parallel execution of three construction projects—a hospital, a building, and a school—detailing each project's Work Breakdown Structure (WBS), cost, time, and resource requirements. Initial calculations of net cash flow excluded potential risks to establish a baseline. We then identified and qualitatively assessed risks impacting the projects, such as delays, cost overruns, and resource shortages. We quantified these impacts using the Value at Risk (VaR) method and Monte Carlo simulation to estimate maximum potential losses with a 95% confidence level. For instance, our model revealed that there is a 5% chance that cash flow deficits could exceed a certain threshold, enabling managers to plan for contingency funding. Recognizing that delays in project timelines can result in substantial fines and increased costs, our approach underscores the importance of considering both cost and time risks to accurately reflect real-world scenarios. Additionally, this study suggests that examining cash flow predictions in a fuzzy environment could provide further insights due to the inherent uncertainties in construction project implementation.

The practical applications of this research are extensive and multifaceted. Our framework, which integrates Value at Risk (VaR) and Monte Carlo simulation, enables construction companies to forecast cash flows with greater accuracy. Project managers can proactively plan contingency funding and allocate resources more effectively by quantifying the potential impact of risks. For example, our model provides a realistic assessment of risk exposure and funding requirements, allowing managers to estimate potential cash flow shortfalls with 95% confidence.

The following are key areas where our framework can be effectively applied:

(1) Construction Projects: In firms managing simultaneous projects across different locations, our methodology allows project managers to forecast cash flows with greater accuracy. By quantifying financial risks, managers can allocate resources effectively, arrange necessary financing in advance, and implement risk mitigation strategies, thereby reducing the likelihood of cash flow shortages and project delays.

(2) Business Management and Economics: By integrating financial risk assessment into project management, our approach provides business managers with a powerful financial planning tool. Finance departments can use the VaR estimates to make informed decisions on capital allocation, investment strategies, and debt management. Enhanced financial planning reduces financial distress and strengthens overall economic stability.

(3) Large-Scale and High-Risk Projects: In megaprojects such as tunnel construction, where financial stakes are higher, our method optimizes risk management strategies. By identifying critical financial risks, firms can prioritize resources for risk mitigation, ensuring projects are

completed on time and within budget. This enhances overall project performance and profitability.

By incorporating Value at Risk (VaR) and Monte Carlo simulation, our framework enables proactive financial planning, reduces cash flow deficits, and improves liquidity management. For example, a construction manager can anticipate cash flow shortfalls, allowing for the strategic allocation of contingency funds. Additionally, the model contributes to better project outcomes and greater financial resilience across the construction sector by enhancing strategic decision-making, helping companies prioritize high-risk projects and ensure adequate funding.

The main benefit of this approach is its ability to provide a continuous assessment of financial and qualitative risks, offering a dynamic and proactive understanding of potential challenges. The integration of VaR represents a valuable addition to the existing risk management framework of the PMBOK, equipping construction managers with a quantitative tool to improve decision-making, anticipate uncertainty, and mitigate risks in complex construction projects.

This research highlights the importance of effective cash flow management in the construction industry and links theoretical insights to practical applications. The proposed framework provides a structured approach for practitioners to handle the complexities of financial management across multiple projects. By demonstrating the effectiveness of advanced risk quantification methods, our study suggests that policymakers could support the adoption of such tools through incentives or industry standards, enhancing the resilience and economic stability of the construction sector. For example, policymakers and regulatory bodies could mandate or encourage the use of risk assessment models like VaR and Monte Carlo simulations for large-scale projects, ensuring firms are better prepared for financial uncertainties. This would protect public investment, ensure efficient project delivery, and reduce the financial exposure of taxpayers.

Improved cash flow management has a positive economic impact that extends beyond the construction industry. It enables better allocation of resources, decreases financial volatility, and promotes higher-quality infrastructure, which is critical for societal development. In addition, a financially stable construction industry creates a more predictable investment environment, boosting economic growth and improving public welfare.

In addition, this research enriches the body of knowledge by providing a solid framework for future studies on risk management and financial strategies in the construction industry. By integrating financial planning with proactive risk management, the framework aims not only to improve project outcomes but also to contribute to societal benefits such as job creation, economic growth, and improved infrastructure. Promoting public awareness of the importance of financial health in construction firms is crucial for maintaining quality of life and supporting sustainable development. The proposed approach to improved cash flow risk management helps ensure the timely completion of critical infrastructure projects, such as hospitals and schools. By enabling construction companies to better manage financial risk, the model reduces delays and resource shortages, resulting in higher-quality projects. This, in turn, leads to increased job stability and sustainable employment opportunities in the construction sector.

Despite its contributions, our study has certain limitations. The model's effectiveness is contingent upon the accuracy of input data and the validity of the assumptions made regarding risk predictability. The applicability of the model may vary across different types and scales of construction projects. Future research could explore the integration of additional risk factors, such as macroeconomic variables or geopolitical events, and test the model's applicability in various contexts, including small and medium-sized construction firms or international projects.

6. Conclusions

By integrating Value at Risk (VaR) and Monte Carlo simulation into a comprehensive cash flow risk management framework, this study achieves its objective of developing a robust and reliable model for enhancing the accuracy and reliability of cash flow predictions and mitigating financial uncertainty, ultimately improving project outcomes. By analyzing the parallel execution of three construction projects, we demonstrate that comprehensive risk analysis significantly enhances the accuracy of cash flow forecasts. Our findings indicate that risks substantially increase project costs and reduce net cash flow, underscoring the critical importance of detailed risk identification and analysis to mitigate these impacts.

The original contribution of this research lies in the development of a novel framework that integrates VaR and Monte Carlo simulation for cash flow prediction and risk management in a multi-project environment. This approach provides a probabilistic assessment of potential financial losses, enabling construction firms to proactively manage financial risks and improve project success rates. By aligning projected and actual cash flows, our framework enhances financial stability and supports effective decision-making in the construction industry.

By integrating VaR and Monte Carlo simulation, this study successfully develops a robust cash flow risk management framework. The primary objective of enhancing the accuracy and reliability of cash flow predictions is achieved by applying advanced risk analysis techniques, which significantly improved prediction accuracy. Our findings indicate that effectively managing financial risk and refining cash flow predictions, as outlined in our objectives, leads to better project outcomes. This model not only provides a probabilistic assessment of financial risk but also enables construction companies to proactively manage these risks, thereby enhancing financial stability. The model's application in a multi-project environment has validated its contribution to the development of a robust predictive framework, aligning with the study's objectives.

Despite these contributions, there are limitations that should be acknowledged. The accuracy of the risk assessment and cash flow predictions depends on the quality and availability of data; inaccurate or incomplete data can lead to erroneous results. Additionally, the model assumes that risks are somewhat predictable, which may not account for unexpected external factors such as economic downturns or regulatory changes. The complexity of managing multiple interdependent projects may also require more sophisticated modeling techniques.

To address these limitations, future research could explore the integration of advanced technologies like machine learning and artificial intelligence to enhance risk prediction accuracy. Developing dynamic risk management frameworks that adapt to changing project conditions and external factors would provide more robust mitigation strategies. Conducting additional case studies across various construction sectors and regions could validate the model's applicability and effectiveness. Furthermore, performing sensitivity analyses would deepen the understanding of how different variables impact cash flow and project outcomes, offering valuable insights for risk management.

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