Primary Risks for Delays and Cost Overruns in the Construction of Drinking Water Supply and Sanitation Projects in Peru

Carlos Julca-Varas[1]; Tatiana García-Segura, Ph.D.[2]; Cristina Torres-Machi, Ph.D., M.ASCE[3]; and Laura Montalbán-Domingo, Ph.D.[4]

Abstract: Delays and cost overruns are common problems in construction projects that may jeopardize construction completion when actual construction times and costs substantially differ from estimates in the planning stage. This study examines the risks that contribute to delays and cost overruns in drinking water supply and sanitation projects in Peru. Descriptive statistics, logistic regressions, and Chi-square tests were applied to: (1) identify the primary risks; (2) analyze the influence of contracting characteristics on the occurrence of delays and cost overruns; and (3) explore the association between delays and cost overruns caused by these risks. The analysis of charge order documents from 318 projects in Peru found that 22 of the risks identified in the literature are present in the reviewed projects, along with five additional risks not described in the literature. The results indicate that the most significant risks in terms of frequency of occurrence include: delay in change orders approvals, adverse weather conditions, inaccurate site information, inaccurate cost estimates at the design stage, and land availability problems. Additionally, the contract amount is the most influential variable in the occurrence of delays and cost overruns. The higher the contract amount, the greater the probability of occurrence. This research provides valuable insights for professionals involved in project management, helping them better understand the primary risks contributing to delays and cost overruns. **DOI: 10.1061/JMENEA.MEENG-6496.**

Practical Applications: Delays and cost overruns frequently affect the number of projects that public administrations complete within a given period, ultimately affecting the population's access to essential infrastructure for basic services such as drinking water and sanitation. Additionally, public administrators usually lack comprehensive information on the risks that may affect the project schedules and costs. This article identifies the frequency of occurrence of the main risks leading to delays and cost overruns on construction projects, highlighting the five most significant ones. The study also finds that the probability of occurrence of delays and cost overruns depends on the contracting characteristics. These findings enable risk managers to prioritize resources effectively. By focusing on the five most significant risks, they can develop more targeted risk management strategies, improving the overall predictability and stability of project outcomes. Furthermore, understanding how contracting characteristics affect project performance allows for the development of better contract procedures.

Author keywords: Delay and cost overruns; Construction projects; Drinking water supply; Sanitation; Risks.

Introduction

A project is deemed successful when it achieves its technical performance, meets its deadline, and stays within budget (Frimpong et al. 2003). However, the escalation of deadlines and costs in public construction projects is a global phenomenon that has persisted for the past 70 years (Flyvbjerg et al. 2002). Construction projects unfold within complex and uncertain environments and involve multiple stakeholders with diverse objectives and inherent risks that can significantly impact project outcomes (Hamzaoui et al. 2015). Timely identification and communication of risks is crucial to effectively manage and mitigate delays and cost overruns and ultimately enhance owner satisfaction (Perrenoud et al. 2016). Conversely, unidentified and unmanaged risks pose threats to the project objectives, leading to cost overruns (Chapman 2001), delays, or even project failure (Derakhshanfar et al. 2019). Elbashbishy et al. (2022) studied 53 construction projects, where 80% of the risks identified have a significant impact on cost overruns, and found that 89% of the risks can be recognized at the start of the project.

Construction delays and cost overruns are a global concern, particularly in public projects financed with taxpayer money (Alinaitwe et al. 2013). The additional costs and time incurred due to project modifications constrain the number of projects that can be completed within a fiscal year (Al-Hazim and Abusalem 2015). Therefore, it is imperative to identify and prioritize the risks contributing to cost overruns before striving to enhance project cost estimation

[1]Ph.D. Candidate, School of Civil Engineering, Universitat Politècnica de València, Camino de Vera s/n, Valencia 46022, Spain. Email: cajulvar@upv.edu.es

[2]Associate Professor, Construction Project Management Research Group, Universitat Politècnica de València, Camino de Vera s/n, Valencia 46022, Spain. ORCID: https://orcid.org/0000-0002-7059-0566. Email: tagarse@upv.es

[3]Assistant Professor, Dept. of Civil, Environmental, and Architectural Engineering, Univ. of Colorado Boulder, 1111 Engineering Dr., Boulder, CO 80309-0428. ORCID: https://orcid.org/0000-0002-4334-4474. Email: cristina.torresmachi@colorado.edu

[4]Associate Professor, Construction Project Management Research Group, Universitat Politècnica de València, Camino de Vera s/n, Valencia 46022, Spain (corresponding author). ORCID: https://orcid.org/0000-0002-9506-0350. Email: laumondo@upv.es

Note. This manuscript was submitted on June 28, 2024; approved on November 1, 2024; published online on February 27, 2025. Discussion period open until July 27, 2025; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Management in Engineering***, © ASCE, ISSN 0742-597X.

accuracy (Shane et al. 2009). Disputes over responsibility and cost allocation often arise in the aftermath of project delays, often escalating to arbitration and, in extreme cases, litigation that has the potential to result in project abandonment (Sambasivan and Soon 2007). Delay claims and extension of time claims are among the 10 most frequent types of claims in construction (Awwad and Thabet 2024).

Within public infrastructure, drinking water and sanitation projects are critical drivers of urban development and public health, evidenced by the correlation between access to these services and a reduction in diarrheal diseases (Fewtrell and Colford 2005). Regarding public health, the health crisis of COVID-2019 highlighted the urgent need to provide greater coverage to the population in drinking water and sanitation services. Access to these services also yields substantial economic benefits, including time savings, increased productivity, reduced healthcare costs, and lives saved (Hutton et al. 2007).

In the Peruvian context, the sanitation sector has received a total budget of $10,070 million between 2014 and 2021, ranking third among sectors with the highest public budget allocation in the country. However, the actual investment execution has averaged only 59.8% annually ($ 6,022 million) (Ministry of Housing Construction and Sanitation 2021). It is estimated that achieving universal access to sanitation services for Peruvians currently requires $ 12,814 million. Population growth will increase by approximately $ 553 million per year, and the need for rehabilitation, improvement, and replacement of infrastructure is estimated to increase by $ 628 million per year (Ministry of Housing Construction and Sanitation 2021). This investment gap is particularly worrisome because of the limited access to these essential services. In 2020, approximately 7.5 million Peruvians (i.e., 23.2% of the population) had no access to sanitation services, and the lack of access to drinking water impacted 2.9 million inhabitants (8.8% of the total population) (Ministry of Housing Construction and Sanitation 2021). Additionally, all the efforts of the Peruvian government to achieve universal access to sanitation services are hindered by the low performance of the projects in terms of time and costs. As of July 2018, 867 projects between civil and buildings were paralyzed at the national level due to risks arising during execution, and 698 additional projects were in arbitration, with deadline extensions being the primary point of contention (Controller General of the Republic 2019). Overall, 2,324 projects have been suspended by March 2024, with a contract amount of $ 8,504 million; 18.4% of this amount corresponds to drinking water and sanitation projects (Controller General of the Republic 2024).

According to the World Competitiveness Center (2024), Peru ranks 63 out of 67 in the global competitiveness ranking. This ranking analyzes economic performance, government efficiency, business efficiency, and infrastructure. In the context of Latin America, Peru is only ahead of Venezuela and Argentina and has shown a downward trend in competitiveness since 2008 (World Competitiveness Center 2024). However, the problems Peru faces are not problems exclusive to this country. These are common challenges faced by developing countries, especially those with low levels of competitiveness that experience structural problems in economic performance, government efficiency, and business efficiency, as well as in the availability and quality of basic infrastructure. Consequently, improving the efficiency of investment in basic infrastructure is critical for enhancing economic growth and improving competitiveness at both the national and regional levels. In this regard, it is essential to highlight that the global economic return on every US dollar invested is estimated to be $5.5 for sanitation and $2 for drinking water supply; however, those for Latin America are estimated at $7.3 and $2.4, respectively (Hutton 2013). Therefore, drinking water and sanitation projects are highly beneficial and cost-effective investments for society.

Knowledge Gap and Goals of the Research

Previous research on delays and cost overruns in the construction industry has analyzed countries across different continents, including America (Shane et al. 2009), Asia (Sambasivan and Soon 2007), Europe (Gündüz et al. 2013; Larsen et al. 2016), and Africa (Abd El-Razek et al. 2008; Bagaya and Song 2016; Elinwa and Joshua 2001). In these studies, causes for cost overruns and delays were identified from surveys or expert opinions. These studies, however, have the limitation that the impact of risks on costs and delays is studied independently, (i.e., studies either analyze the impact on time or on costs), and impacts on both time and cost are often overlooked. Also, existing research predominately relies on retrospective opinions gathered through surveys or interviews (Siraj and Fayek 2019) rather than empirical data derived from project execution reports—an approach that is crucial for identifying precise risks contributing to delays and cost overruns.

While various authors agree that the same factors causing delays may also lead to cost overruns (Kaliba et al. 2009; Sambasivan and Soon 2007), there is also evidence that these factors do not equally affect the schedule, cost, and quality of the project (Larsen et al. 2016). The main effects of delays and cost overruns are: poor quality, project abandonment, litigation, and project prolongation (Kaliba et al. 2009). Therefore, the analysis of project delays should take a holistic view, considering the potential impacts on cost and quality (Santoso and Soeng 2016). Furthermore, while research into the causes of delays and cost overruns looks for the influence of aspects such as project complexity, location, type of project, and contract size, it does not consider the influence of contracting characteristics, such as award coefficient, payment strategy, or time lag between approval of the project and start date of work, among others.

Despite extensive research on delays and cost overruns in construction projects worldwide, limited attention has been given to exploring the key risks affecting the duration and costs of constructing drinking water supply and sanitation projects. For example, some authors have studied these risks in road projects (Kaliba et al. 2009; Mahamid et al. 2012; Santoso and Soeng 2016), building projects (Abd El-Razek et al. 2008; Alaghbari et al. 2007), and construction projects in general (Bagaya and Song 2016; Gündüz et al. 2013; Larsen et al. 2016). These aspects have been explored to a lesser extent in groundwater (Frimpong et al. 2003) and oil and gas projects (Ruqaishi and Bashir 2014). However, Bhargava et al. (2010) highlight that delays and cost overruns in different types of projects may differ due to construction practices and planning processes specific to each project. Consequently, there is a need to analyze delays and cost overruns in drinking water supply and sanitation projects in Peru.

The main objective of this study is to analyze delays and cost overruns in drinking water supply and sanitation projects, with three specific research goals: (G1) identify the main risks contributing to delays and cost overruns; (G2) determine the contracting characteristics significantly influencing delays and cost overruns; and (G3) analyze the degree of association between delays and cost overruns caused by each identified risk.

Research Method

The first step of this study aimed at developing a comprehensive literature review to identify the risks leading to delays and cost overruns in construction projects worldwide. The result was the definition of a risk breakdown structure (RBS) in order to classify

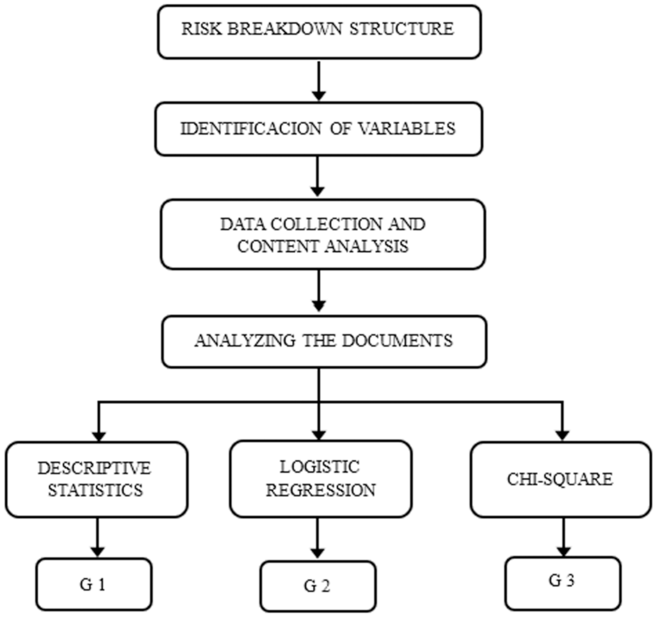


Fig. 1. Research process.

the risks into categories and subcategories. Then, the identification of variables was carried out in which the contracting characteristics to be analyzed were defined. Subsequently, to characterize the delays and cost overruns in drinking water supply and sanitation Peruvian projects, change order documents in drinking water supply and sanitation projects in Peru were collected, and a content analysis was performed to extract the information from these documents. Once the data were extracted, descriptive statistical analyses were conducted to identify the primary risks contributing to delays and cost overruns (G1). Following this, logistic regression analyses were employed to identify the contracting characteristics significantly influencing delays and cost overruns (G2). Finally, the degree of association between delays and cost overruns attributable to each risk was analyzed using the Chi-square test (G3). The alignment of these analyses with the research goals is depicted in Fig. 1.

Risk Breakdown Structure

The RBS is a common and practical tool widely used in risk management during the different stages of projects (Hamzaoui et al. 2015). This tool can be used to identify risks and support later stages of the process (Chapman 2001). According to Derakhshanfar et al. (2019), a RBS groups risk into categories based on the source of risks. Siraj and Fayek (2019) recommend categorizing risks according to their nature and conclude that a three-level RBS (i.e., main category, subcategory, and risks at the lowest level) is the most common practice among different authors.

To identify the categories and risks, a systematic literature review was carried out from Scopus. Keywords used for the search were: "delay" or "cost overrun" and "projects construction," resulting in more than 500 papers. With the results obtained, we initially filtered those papers published in the last 20 years, selecting those whose titles indicated a strong relevance to the current research topic, specifically, the identification of delay risks or cost overrun risks in construction projects. This process yielded a final selection of 21 papers. Then, a thorough review of the documents was carried out with the objective of identifying the risks and the categories. The main categories used for risk classification were established following the recommendations of Bagaya and Song (2016) and Ruqaishi and Bashir (2014). Table 1 shows the adopted RBS and references in the literature for each one on the risks associated.

The first level summarizes the categories (i.e., stakeholders, contract, resources, unforeseen conditions in execution), the second level comprises subcategories (i.e., owner, consultant/designer, direct and indirect users of the project, government agents, other entities, contractual relationships between the parties, materials and equipment, natural causes, strikes and vandalism, and site conditions), and the final level defining the risks. The risks belonging to the contractor subcategory are outside the scope of the present research since the source of information was change order documents where the contractor is granted additional time or costs. According to Peruvian regulations, change orders are approved when the contractor has no responsibility for the resulting modifications.

Identification of Variables

In order to determine the contracting characteristics significantly influencing delays and cost overruns, the research team identified through a literature review the characteristics of tendering documents to be analyzed as a starting point (Table 2). These were classified into two groups: (1) contractual framework; and (2) execution conditions.

The variables included in the contractual framework are as follows: payment strategy, owner, nature of intervention, and initial contract amount. In terms of payment strategy, lump sum payment is considered an effective option to keep projects within budget because the nature of the contractual agreements establishes that the contractor must submit its bid with estimated quantities and a total cost for the project, minimizing cost growth. However, the lump sum payment strategy does not guarantee meeting deadlines in large-scale projects (Choi et al. 2021); therefore, this variable should be taken into account. Gómez-Cabrera et al. (2020) have shown that the type of owner significantly influences both delays and cost overruns, and this may be influenced by the amount of resources allocated and the management capacity of public administrations.

On the other hand, due to the inherent construction practices and processes associated with different types of projects, delays and cost overruns may vary depending on the type of project (Bhargava et al. 2010; Huo et al. 2018). Along these lines, it is important to analyze the variable nature of intervention within water supply and sanitation projects. The contract amount also significantly influences delays and cost overruns, with larger projects experiencing greater delays and cost overruns (Gómez-Cabrera et al. 2020). However, Bhargava et al. (2010) found that the effect of the explanatory variable contract amount may vary depending on the type of project.

On the other hand, four variables were identified for the execution conditions group: geographical region, area of execution, award coefficient, and time lag between approval of the project and start date of work. The award coefficient is a variable worth analyzing, as several authors have pointed out that awarding the project to the lowest bidder is one of the most important causes of delay (Mahamid et al. 2012; Santoso and Soeng 2016) as well as cost overruns (Rosenfeld 2014). This may be justified because the lowest bidders are less qualified contractors with limited resources and insufficient experience, resulting in poor project performance (Mahamid et al. 2012; Santoso and Soeng 2016). Concerning cost overruns, Odeck (2004) identified significant differences depending on the geographical location of the projects, related to characteristics such as the topography of each region. Likewise, Bhargava et al. (2010) concluded that weather conditions have a significant influence on the occurrence of delays and cost overruns. Therefore, it is

Table 1. Risk breakdown structure

Category	Subcategory	Risk	References
Stakeholders	Owner	Delay in payment to a contractor	Abd El-Razek et al. (2008), Bagaya and Song (2016), Elinwa and Joshua (2001), El-Sayegh and Mansour (2015), Frimpong et al. (2003), Gündüz et al. (2013), Kaliba et al. (2009), Mahamid et al. (2012), Odeh and Battaineh (2002), Ruqaishi and Bashir (2014), Sambasivan and Soon (2007), and Santoso and Soeng (2016)
		Land availability problems	El-Sayegh and Mansour (2015), Gündüz et al. (2013), Mahamid et al. (2012), and Santoso and Soeng (2016)
		Changes in project scope	Abd El-Razek et al. (2008), Alaghbari et al. (2007), Bagaya and Song (2016), Gündüz et al. (2013), Kaliba et al. (2009), Larsen et al. (2016), Mahamid et al. (2012), Odeh and Battaineh (2002), Ruqaishi and Bashir (2014), Sambasivan and Soon (2007), Santoso and Soeng (2016), and Shane et al. (2009)
		Delay in change order approvals	El-Sayegh and Mansour (2015), Gündüz et al. (2013), Mahamid et al. (2012), and Santoso and Soeng (2016)
	Consultant/Designer	Redesign due to changes in the original technical design	Abd El-Razek et al. (2008), Elinwa and Joshua (2001), El-Sayegh and Mansour (2015), Gündüz et al. (2013), Kaliba et al. (2009), Mahamid et al. (2012), and Santoso and Soeng (2016)
		Inaccurate cost estimates at the design stage	Frimpong et al. (2003), Santoso and Soeng (2016), and Shane et al. (2009)
		Inaccurate soil survey	Abd El-Razek et al. (2008), Gündüz et al. (2013), and Larsen et al. (2016)
		Errors and discrepancies in design documents	Abd El-Razek et al. (2008), Alaghbari et al. (2007), Gündüz et al. (2013), Larsen et al. (2016), Mahamid et al. (2012), and Santoso and Soeng (2016)
		Inadequate methods for quality control and quality assurance	Abd El-Razek et al. (2008), Bagaya and Song (2016), Frimpong et al. (2003), Odeh and Battaineh (2002), Ruqaishi and Bashir (2014), and Sambasivan and Soon (2007)
		Inaccurate site information	Gündüz et al. (2013)
		Lack of adequate consultation with the water authority and/or Ministry of Culture in the design stage	El-Sayegh and Mansour (2015)
	Direct and indirect users of the project	Claims from project users	Gündüz et al. (2013) and Ruqaishi and Bashir (2014)
	Government agents and other entities	Availability/authorization of utilities on site (water, electricity)	Gündüz et al. (2013)
		Interruption of works from public entities	Alaghbari et al. (2007)
		Governmental permits	Abd El-Razek et al. (2008), Bagaya and Song (2016) Gündüz et al. (2013), and Santoso and Soeng (2016)
		Regulatory changes	Alaghbari et al. (2007) El-Sayegh and Mansour (2015), Gündüz et al. (2013), Odeh and Battaineh (2002), Ruqaishi and Bashir (2014), Sambasivan and Soon (2007), and Santoso and Soeng (2016)
Contract	Contractual relationship between the parties	Legal disputes between parties	Bagaya and Song (2016), Elinwa and Joshua (2001), Gündüz et al. (2013), Larsen et al. (2016), Mahamid et al. (2012), Odeh and Battaineh (2002), Ruqaishi and Bashir (2014), and Sambasivan and Soon (2007)
Resources	Materials and equipment	Shortage of materials and/or equipment	Abd El-Razek et al. (2008), Alaghbari et al. (2007), Bagaya and Song (2016), Elinwa and Joshua (2001), Frimpong et al. (2003), Gündüz et al. (2013), Kaliba et al. (2009), Mahamid et al. (2012), Odeh and Battaineh (2002), Ruqaishi and Bashir (2014), Sambasivan and Soon (2007), and Santoso and Soeng (2016)
Unforeseen conditions in execution	Natural causes	Adverse weather conditions	Abd El-Razek et al. (2008), Alaghbari et al. (2007), Bagaya and Song (2016), Elinwa and Joshua (2001), El-Sayegh and Mansour (2015), Frimpong et al. (2003), Gündüz et al. (2013), Kaliba et al. (2009), Larsen et al. (2016), Mahamid et al. (2012), Odeh and Battaineh (2002), Ruqaishi and Bashir (2014), Sambasivan and Soon (2007), and Santoso and Soeng (2016)
	Strikes and vandalism	Demonstrations/strikes	Gündüz et al. (2013), Kaliba et al. (2009), Mahamid et al. (2012), and Santoso and Soeng (2016)
	Site conditions	Inaccessibility to the worksite	Mahamid et al. (2012) and Santoso and Soeng (2016)
		Unforeseen worksite conditions	Abd El-Razek et al. (2008), Alaghbari et al. (2007), Bagaya and Song (2016), Frimpong et al. (2003), Gündüz et al. (2013), Larsen et al. (2016), Mahamid et al. (2012), Odeh and Battaineh (2002), Sambasivan and Soon (2007), Santoso and Soeng (2016), and Shane et al. (2009)

Table 2. Contracting characteristics and defined categories for the logistic regression

Group	Variable name	Category	Source
Contractual framework	Payment strategy	0: Lump sum; 1: Unit prices	Choi et al. (2021)
	Owner	0: National; 1: Regional; 2: Provincial	Gómez-Cabrera et al. (2020)
	Nature of intervention	0: New construction; 1: Improvement and/or extension	Bhargava et al. (2010) and Huo et al. (2018)
	Initial contract amount	0: Less than \$250,000; 1: \$250,000 to \$1 million; 2: More than \$1 million	Bhargava et al. (2010) and Gómez-Cabrera et al. (2020)
Execution conditions	Geographical region	0: Coast; 1: Countryside; 2: Jungle	Bhargava et al. (2010) and Odeck (2004)
	Area of execution	0: Rural; 1: Urban	Bhargava et al. (2010) and Huo et al. (2018)
	Time lag between approval of the project and start date of work	0: Less than 9 months; 1: Between 9 and 18 months; 2: more than 18 months	Flyvbjerg et al. (2004)
	Award coefficient	0: $0.90 \leq C < 1.00$; 1: $1.00 \leq C \leq 1.10$	Mahamid et al. (2012), Rosenfeld (2014), and Santoso and Soeng (2016)

relevant to analyze the variable geographic region, especially in Peru, where topography and weather conditions vary considerably between regions. Finally, Flyvbjerg et al. (2004) found a positive relationship between the time elapsed from the decision to build to the start of construction and project cost overruns.

Data Collection and Content Analysis

To analyze delays and cost overruns in drinking water supply and sanitation projects, information about the performance of Peruvian construction projects was collected. Change order documents were collected from the public access platform InfObras of the Peruvian government (Controller General of the Republic 2021). The InfObras web portal was used to retrieve information on drinking water supply and sanitation projects registered on the portal as of July 2021 (Controller General of the Republic 2021). The following filters were established: (1) completed projects; (2) projects executed by public contract; and (3) projects funded by a public (i.e., national, regional, or provincial) agency. According to these filters, 1,781 contracts were identified. Then, the following equation was used to determine the sample of analysis (Vivanco 2005):

$$n = \frac{Z^2 \times 0.25 \times N}{e^2(N-1) + Z^2 \times 0.25} \quad (1)$$

where n = sample size; N = population size (1,781 contracts); Z = confidence level (for 95%, $Z = 1.96$); and e = maximum permissible error (5%).

A sample of 316 projects was estimated to be statistically representative of carrying out this research. The information was collected from contracts with complete information on the platform (i.e., resolutions of schedule extensions and additional costs, start and finish dates of the project, and project liquidation document). Based on these criteria, information was collected from 318 randomly selected contracts completed between 2010 and 2021 (see List of analyzed projects).

Subsequently, the information was extracted from these documents through a content analysis. Content analysis is a research technique that allows replicable and valid inferences to be drawn from the data to the context of their use; it also allows for the analysis of large volumes of written material (Krippendorff 2004). According to the recommendations of Stanford et al. (2016) and Montalbán-Domingo et al. (2019), the content analysis of this study was based on five tasks: defining the protocol, collecting documents modifying projects, reviewing documents according to the protocol, establishing interrater reliability, and statistically analyzing the data.

In this research, the protocol to guide the content analysis was elaborated according to the recommendations of Stanford et al. (2016) and Montalbán-Domingo et al. (2019). This protocol established the coding procedure, the variables of interest in the research, the recommended search terms, and examples of typical expected results. The protocol was developed considering the results of the literature review in terms of risks and contracting characteristics.

The charge order documents from 318 projects in Peru were then analyzed according to the protocol. To ensure the objectivity of the analysis and guarantee the correct application of the content analysis, interrater reliability was measured for each variable. Considering the recommendations of Stanford et al. (2016), two coders reviewed the documents of a random project to refine the coding process and ensure consistency of analysis. Then, 35 projects were randomly selected, more than 10% of the total documents collected (Cohen 1960), to code them independently and measure interrater reliability. Percent interrater agreement (PA_o) was calculated for continuous variables, and Cohen's kappa (Cohen 1960) was selected to calculate the interrater reliability for discrete variables. According to Stanford et al. (2016), PA_o is a widely used and easily understood measure for determining interrater agreement. The observed agreement ratio is calculated as the number of interrater agreements divided by the total number of units coded by both raters. Cohen's kappa is calculated as follows:

$$k = (PA_o - PA_g)/(1 - PA_g)$$

where PA_o = proportion of agreement observed; and PA_g = proportion of agreement expected by chance [for more details the calculation of PA_g review Cohen (1960)]. PA_o and k, range from 0.0 to 1.0, where 1.0 indicates perfect agreement (Stanford et al. 2016). From the calculations performed for each variable in this research, the interrater reliability yielded values greater than 0.8, which is considered satisfactory according to Neuendorf (2017).

Statistical Analysis

After collecting the documents, the initial phase involved extracting information about each project's risks, contracting characteristics, delays, and cost overruns (see Table S1 in Supplemental Materials). We utilized the RBS derived from the literature review as the basis to identify the principal risks contributing to delays and cost overruns in drinking water supply and sanitation projects (G1). Subsequently, we identified the primary risks leading to delays and cost overruns in the projects analyzed, determining the frequency

J. Manage. Eng., 2025, 41(3): 04025008

of occurrence for each risk within the sample and assessing their impact on time and cost.

To address G2, which aims to identify contracting characteristics significantly influencing the occurrence of delay and cost overruns, we gathered information on several factors including the award coefficient, payment strategy, owner, geographical region, area of execution (i.e., urban or rural), nature of intervention, initial contract amount, and time lag between approval of the project and start date of work. In terms of geographic region, Peru is divided into three regions: coast (i.e., Peruvian coast with minimal rainfall conditions), countryside (i.e., characterized by rugged terrain with an average altitude of 3,000 meters and a rainy season between November and April), and jungle (i.e., area of the country with the most frequent rainfall and rainy season similar to the one of the countryside regions). With respect to the area of execution, rural areas are characterized by a population of less than 2,000 inhabitants, whereas urban areas have a population larger than 2,001. The Peruvian government is structured in three levels: national, regional, and provincial. Finally, the award coefficient is the ratio between the award budget (the budget by which the project is awarded to the winning contractor) and the bid budget (the budget for which the project is offered by the public agency). Data on delay and cost overruns for each project were extracted, detailing the risks that gave rise to these deviations in deadline and cost.

Once the database was compiled, a series of analyses were conducted to ensure the validity of the data. First, we assessed the normality of the data using the Kolmogorov–Smirnov test. Subsequently, we examined multicollinearity among variables and risks to identify highly correlated elements. This involved analyzing correlations using Spearman's coefficient, which allows for the detection of correlations exceeding 0.8, indicative of strong relationships between variables (Field 2009).

The statistical technique of binary logistic regression was employed. This technique enables the prediction of categorical outcomes from predictor variables (Field 2009) and is commonly used to identify variables demonstrating a strong relationship with the dependent variable (Montalbán-Domingo et al. 2019). Two separate logistic regression analyses were conducted—one for delay and one for cost overrun—given that the dependent variable is categorical with two possible outcomes (0: does not occur; 1: occurs). The contracting characteristics listed in Table 2 were utilized as independent variables. Numerical variables were transformed into categorical variables to facilitate the analysis and interpretation of results. To establish the ranges for the categories of the variable's initial contract amount and the time lag between project approval and the start date of work, initially, different ranges were established. For the case of the contract amount, ranges were established at every \$ 250,000, and for the time lag, it was every 3 months, verifying whether they presented significant differences between them. Then, the ranges that did not show significant differences, i.e., p-value > 0.05, were grouped together. Finally, the intervals that presented significant differences are shown in Table 2.

Binary logistic regression analysis was conducted using IBM SPSS, employing the stepwise model, which is recommended when reliable predictors are uncertain (Field 2009). A confidence interval of 95% was established for the exponential Beta. Nagelkerke's R^2 statistics were utilized to evaluate the logistic regression model, as alternatives to this statistic (i.e., the Cox and Snell R^2 statistic) may not reach its theoretical maximum of 1 (Field 2009). In determining the significance of independent variables, the level of significance of the Wald statistic associated with each variable needed to be less than 0.05. This indicates that the predictor variable significantly contributes to the model; moreover, a higher Wald value suggests a greater contribution of that predictor (Field 2009). For interpreting the results, exp(B) values greater than 1 indicate that the probability of the outcome occurring increases as the predictor increases. Conversely, values less than 1 suggest that as the predictor increases, the likelihood of the outcome decreases (Field 2009). It is important to note that in logistic regression, interpretation always involves comparing two categories of a predictor; thus, a reference category was established for all variables to facilitate the interpretation of the results (Field 2009).

Finally, for G3, the degree of association between delay and cost overruns caused by each risk was analyzed. This analysis is performed to assess whether the occurrence of a risk impacts both time and cost. For this purpose, the Chi-square test was deemed appropriate, as it allows the study of the relationship between two categorical variables (Field 2009). The phi coefficient was the statistic used to measure the degree of association, which ranged from 0, representing no association, to 1, representing perfect association (Field 2009).

Results and Discussion

Sample Characterization

A total of 318 project contracts were analyzed. Table 3 illustrates that 52% of the projects were awarded with an initial contract amount between \$ 250,000 and \$1 million, and 60% of the contracts were awarded with an amount greater than the bidding amount. In turn, the unit price payment strategy was the most prevalent strategy used in more than 60% of the projects. Most of the projects (i.e., 77%) consisted of expansion and/or improvement projects. 69% of the projects started construction in less than 9 months after the approval of the project. In addition, the projects are mainly funded by a provincial agency (68%) in an urban area (62%). In terms of geographic region, the largest number of projects analyzed is concentrated in the countryside region (45%).

Occurrence of Delays and Cost Overruns

The analysis of the 318 projects reveals that 39.9% experienced neither delay nor cost overrun, while 55.7% encountered delays, 44.7% faced cost overruns, and 40.3% of the total projects experienced both delay and cost overrun.

These findings suggest that project schedule estimates are generally less accurate than cost estimates or that schedule management is less efficient than construction cost management. It may also imply that public administrations may be more inclined to grant extensions rather than incur additional costs for the contractor. These results align with a study on transportation project findings in Florida that found 61.1% of the projects resulted in cost overruns, 69.4% in delays, and 46.0% encountered both delay and cost overruns (Choi et al. 2021). Similarly, Faridi and El-Sayegh (2006) found that 50% of construction projects in the United Arab Emirates failed to meet schedule deadlines. Al-Momani (2000) highlighted even higher rates of delay, with 81.5% of public projects in Jordan experiencing delays. A study on rural roads in Colombia found that 23.2% of the projects were delayed and 26.9% resulted in cost overruns (Gómez-Cabrera et al. 2020). Results found in the analysis of sanitation projects in Peru suggest alignment with previous studies and reinforce the importance of identifying risks early in the process to reduce the potential occurrence of delays and cost overruns.

Table 3. Summary of the data sample

Initial contract amount		Award coefficient		Payment strategy		Nature of intervention		Time lag between approval of the project and start date of work			Owner			Geographical region			Area of execution	
Description	#	$0.90 \leq C < 1.00$ (%)	$1.00 \leq C \leq 1.10$ (%)	Unit prices (%)	Lump sum (%)	New construction (%)	Improvement and/or extension (%)	Less than 9 months (%)	Between 9 and 18 months (%)	More than 18 months (%)	National (%)	Regional (%)	Provincial (%)	Coast (%)	Countryside (%)	Jungle (%)	Rural (%)	Urban (%)
Less than \$ 250,000	99	48	52	55	45	31	69	79	16	5	10	12	78	35	47	17	41	59
\$ 250,000 to \$ 1 million	165	33	67	58	42	20	80	67	21	12	14	17	69	33	49	18	41	59
More than \$ 1 million	54	46	54	74	26	17	83	56	22	22	28	24	48	50	26	24	22	78
Total	318	40	60	60	40	23	77	69	19	12	15	17	68	37	45	18	38	62

Main Risks

A total of 27 risks associated with delay and cost overruns were identified. Among these, 22 were consistent with findings from the literature review, while five additional risks were identified during the analysis of order changes. An example of these risks can be found in the "Supplemental Materials" section. These additional risks include: Delay in responding to inquiries (R-5), Administrative silence in response to requests from the contractor (R-6), Appointment of a work supervisor (R-7), Permission from the service provider to carry out work on existing building sites (R-16), and COVID-19 state of emergency (R-27).

Table 4 provides a summary of the frequency of each risk in the projects analyzed. Remarkably, risks with a frequency of occurrence exceeding 10% (highlighted in bold) include: delay in change order approvals, adverse weather conditions, inaccurate site information, inaccurate cost estimates at the design stage, and land availability problems. Among these risks, only delays in change order approvals, adverse weather conditions, and land availability problems are prevalent in more than 10% of contracts experiencing delays. Conversely, inaccurate site information and inaccurate cost estimates at the design stage are found in more than 10% of contracts facing cost overruns.

The land availability problems present a significant challenge in the execution of drinking water supply and sanitation projects, as the required land for infrastructure construction is typically privately owned and processes for eminent domain introduce complexities. Various studies underscore the critical nature of this risk across different countries and project types. For instance, it has been identified as a primary cause of delay in road projects in Cambodia (Santoso and Soeng 2016) and the United Arab Emirates (El-Sayegh and Mansour 2015) and in drinking water and wastewater supply projects in Iran (Feyzbakhsh et al. 2018). The likelihood of encountering this risk is amplified in linear infrastructure projects due to the high demand for land areas.

In the Peruvian context, the acquisition of land for construction is typically facilitated through the purchase and sale agreements or donations signed by the landowners during the project planning stage. However, complications often arise during execution, as the condition of the land may change, i.e., the land may have been earmarked for other purposes such as the construction of homes, or the owners may have additional claims to the land when construction starts, which can occur months or even years after initial agreements are made. Land acquisition is inherently a complex negotiation process that can extend over weeks or months. The process is further complicated by disagreements over compensation or land prices, making the process of eminent domain challenging. In Cambodia, for example, researchers have highlighted that conflicts over land acquisition for infrastructure projects are rife, with landowners frequently disputing the compensation offered by the administration, claiming it falls below market value (Santoso and Soeng 2016).

The risk posed by adverse weather conditions emerged as the second most prevalent concern. Peru typically experiences a rainy season from November to March, particularly affecting regions such as the countryside and jungle. Drinking water supply and sanitation projects involve work in large, open areas, making these projects more vulnerable to rainfall. Furthermore, even if rainfall does not occur directly at the construction site, it can limit the transportation of materials and equipment. This risk consistently impacts project timelines, although it rarely affects costs directly. However, in instances where overhead costs are incurred by the contractor or when infrastructure needs relocation, financial implications from rainfall may arise. Such findings align with previous research where adverse weather conditions are identified as a primary cause of

Table 4. Frequency of risks of delay and cost overruns

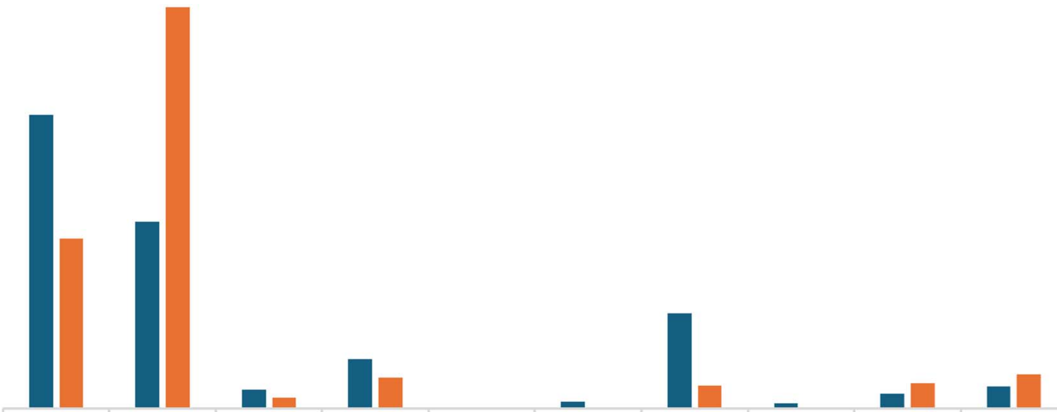
Category	Subcategory	N°	Risk	Projects (%)	Delay (%)	Cost overrun (%)
Stakeholders	Owner	R-1	Delay in payment to a contractor	0.6	0.6	0.3
		R-2	Land availability problems	10.7	10.7	4.1
		R-3	Changes in project scope	8.2	6.0	7.9
		R-4	Delay in change order approvals	20.8	20.8	3.1
		R-5	Delay in responding to inquiries	4.7	4.7	1.6
		R-6	Administrative silence in response to requests from the contractor	5.3	5.3	1.6
		R-7	Appointment of work supervisor	0.3	0.3	0
	Consultant/Designer	R-8	Redesign due to changes in the original technical design	9.1	7.2	8.5
		R-9	Inaccurate cost estimates at the design stage	11.0	2.2	10.1
		R-10	Inaccurate soil survey	6.0	4.4	5.3
		R-11	Errors and discrepancies in design documents	9.4	6.0	8.2
		R-12	Inadequate methods for quality control and quality assurance	0.3	0.3	0.3
		R-13	Inaccurate site information	12.3	8.5	11.3
		R-14	Lack of adequate consultation with the water authority and/or Ministry of Culture in the design stage	2.2	2.2	0
	Direct and indirect users of the project	R-15	Claims from project users	3.5	3.1	1.3
	Government agents and other entities	R-16	Permission from the service provider to carry out work on existing building sites	2.5	2.5	0.6
		R-17	Availability/authorization of utilities on site (water, electricity)	0.9	0.9	0.3
		R-18	Interruption of works from public entities	1.9	1.9	0.6
		R-19	Governmental permits	2.5	2.5	0.9
		R-20	Regulatory changes	0.9	0.3	0.9
Contract	Contractual relationship between the parties	R-21	Legal disputes between parties	0.3	0.3	0
Resources	Materials and equipment	R-22	Shortage of materials and/or equipment	1.3	1.3	0
Unforeseen conditions in execution	Natural causes	R-23	Adverse weather conditions	15.7	15.7	2.5
	Strikes and vandalism	R-24	Demonstrations/strikes	0.9	0.9	0
	Site conditions	R-25	Inaccessibility to the worksite	0.3	0.3	0
		R-26	Unforeseen worksite conditions	3.5	2.2	2.8
	COVID	R-27	COVID-19 state of emergency	3.8	3.8	3.8

delays in road projects (Santoso and Soeng 2016). Similarly, in Zambia, this risk contributes significantly to cost overruns in road projects (Kaliba et al. 2009), while in Jordan, it leads to both delays and cost overruns (Al-Hazim and Abusalem 2015). Moreover, Santoso and Soeng (2016) point to adverse weather conditions as one of the most frequently cited risks in construction literature worldwide. To mitigate the impact of this risk, project planning should carefully consider potential disruptions caused by adverse weather. Santoso and Soeng (2016) propose strategies such as avoiding work during the rainy season or, if unavoidable, meticulously planning construction activities to minimize the impact of rainfall. To mitigate possible weather-related claims, Awwad and Thabet (2024), propose to establish sustainability requirements in the design and implementation stages.

Inaccurate costs estimated at the design stage often result in underestimations of actual costs and are often due to general errors or omissions in drawings and quantities by the consultant (Shane et al. 2009) due to inexperience and lack of responsibility (Liu et al. 2017). Koo and O'Connor (2021) determined that designer inexperience increases the likelihood of defects in the design. From the owner's perspective, this situation occurs exclusively in projects executed under a unit price payment strategy since this risk is transferred to the contractor in lump sum payment strategies. A study in the United Arab Emirates found this risk to be one of the most important risks causing cost overruns (Johnson and Babu 2020). Moreover, Shane et al. (2009) showed that cost estimation problems are not limited to one owner or type of project, but rather a systematic risk. Along these lines, Flyvbjerg et al. (2002) found that 9 out of 10 transportation projects underestimate costs, and this may be a result of the process followed to estimate the economic viability of projects, especially in developing countries.

Regarding the risk of delay in change order approvals, it is interesting to see how this risk has not been identified in previous research as a potential reason for delays and cost overruns. In our study, the risk of delay in change order approvals is the risk that appears most frequently in the sample and the one that occurs most often in terms of delays. While it is true that when this risk occurs, it mostly impacts timelines; sometimes it may produce higher costs for the contractor due to the extensions of the deadline granted, which would ultimately increase project costs. This risk is related to the management of the construction modifications by the parties involved, i.e., the contractor, the project management, and, above all, the developer. Also, it should be considered that the Peruvian regulatory framework requires that before any modification to the construction project is approved, the administration must request a technical assessment from the design team, requiring more time to deal with these modifications.

The risk of inaccurate site information is the most frequent risk from the cost perspective. This risk primarily falls within the purview of the consultant during the design phase. The consultant's level of responsibility and expertise plays a pivotal role in detecting potential omissions or defects in a timely manner. However, instances of oversight or inadequate attention to detail may lead to inaccuracies in assessing the project's current status (Liu et al. 2017); therefore, when this risk arises during the execution, the contractor is liable for an additional cost. Ahmed and El-adaway (2023)



	Owner	Consultant/ Designer	Direct and indirect users of the project	Government agents and other entities	Contractual relationship between the parties	Materials and equipment	Natural causes	Strikes and vandalism	Site conditions	Covid
Delays	42.1%	26.8%	2.7%	7.1%	0.3%	1.1%	13.7%	0.8%	2.2%	3.3%
Cost overruns	24.4%	57.4%	1.7%	4.5%	0.0%	0.0%	3.3%	0.0%	3.7%	5.0%

Fig. 2. Contribution of subcategories to the occurrence of delays and cost overruns risks.

identified those significant differences between site conditions during execution and what is indicated in the contract documents as one of the main causes of litigation in project construction. This risk is primarily associated with soil and topography studies, often subcontracted by the main contractor without direct oversight. However, this practice is not recommended, particularly in projects characterized by diverse soil types and terrains. Given the considerable variability in soil composition and terrain features in linear projects, special attention is needed to anticipate potential challenges during project execution. Contrary to our findings, this risk is not mentioned in studies on Turkey's primary causes of delays in construction projects (Gündüz et al. 2013). This discrepancy can be attributed to the specific nature of drinking water supply and sanitation projects, which entail extensive field data collection efforts across vast land areas. However, compared to road projects, this type of project requires greater precision in terms of topographic studies because the pipelines are commonly buried and require minimum pressures and slopes to operate correctly. Even in improvement and/or extension projects, gathering information from existing underground utilities adds complexity to the data collection process. Consequently, the inherent challenges associated with data collection often require assumptions during the design phase, which may later prove to be inaccurate during project execution.

Fig. 2 shows that the owner is the subcategory that contributes the most to the occurrence of risks that have an impact on the schedule with 42.1% of the cases, followed by the consultant/designer with 26.8%. The owner's contribution is mainly due to (1) delays in the approval of project modification documents; (2) delays in the release or delivery of land for the construction of infrastructure; and (3) changes in the scope during execution, e.g., an increase in the number of beneficiaries, leading to more scope.

Concerning risks impacting costs, the consultant/designer emerges as the primary contributor, accounting for 57.4%, followed by the owner at 24.4%. This indicates that a significant portion of cost-impacting risks during project execution stem from deficiencies in the design phase and fall under the consultant's responsibility. This substantial contribution can be attributed to inadequate field data collection and processing during design. Factors contributing to this include: (1) inaccurate gathering of project site information, particularly regarding topography and geotechnical aspects; (2) erroneous estimates of costs and/or quantities; and (3) design errors requiring redesigns during execution. Conversely, subcategories such as contractual relationships between parties, materials and equipment, strikes, and vandalism exhibited no significant impacts on costs.

These results somewhat align with findings from other studies where the owner emerges as the primary contributor to delays in construction projects (Elinwa and Joshua 2001; Odeh and Battaineh 2002). Conversely, Larsen et al. (2016) identified that four of the top five factors with the greatest effect on cost are attributed to the consultant. These findings underscore the importance of the owner's management capability in ensuring timely project completion while emphasizing the consultant's pivotal role in meeting project requirements within budget constraints. However, Rosenfeld (2014) highlights that consultants themselves have acknowledged that the allocated budgets for design are often insufficient, thereby impacting the quality of design.

Influence of Contracting Characteristics on the Occurrence of Delay and Cost Overruns

Once the risks had been identified, the influence of contracting characteristics on the occurrence of delay and cost overruns was analyzed. Two logistic regressions were performed, one considering delays as the dependent variable and the other one for cost overruns (in both cases, the occurrence of delays and cost overruns were coded as a binary variable, 0: does not occur, 1: occurs). The independent variables were award coefficient, payment strategy, owner, geographical region, area of execution, nature of the intervention, initial contract amount, and time lag between approval of the project and start date of work (see Table 2). To facilitate interpretation, the tables only show the results associated with variables showing statistical significance (p-value < 0.05). Within these variables, those categories that did not show significant differences were grouped together. The logistic regression models obtained with the Nagelkerke R^2 model fit explain 23.4% of the variance when modeling delays as the dependent variable, and 23.3% for the case of cost overrun.

Table 5 summarizes the results of the logistic regression with delays as the dependent variable. The contract amount is the variable with the greatest significant influence with a Wald value of 31.159, followed by the award coefficient (Wald = 8.857) and the owner (Wald = 7.452). With respect to the odds ratios (Exp (B))

Table 5. Logistic regression results with contract delay as the dependent variable

Independent variable	B	Standard error	Wald	gl	Sig.	Exp (B)
Award coefficient: 0–1	−0.796	0.267	8.857	1	0.003	0.451
Owner: 0–1	1.043	0.382	7.452	1	0.006	2.838
Contract amount	—	—	31.159	2	0.000	—
Contract amount: 0–1	0.982	0.280	12.286	1	0.000	4.621
Contract amount: 0–2	2.521	0.470	28.829	1	0.000	31.239

Note: B = regression coefficients; gl =degrees of freedom; Wald = Wald statistic; Exp (B) = log-odds of success; and Sig. = 2-tailed p-value (significant if <0.05). Award coefficient: 0 = 0.90 ≤ C < 1.00; 1 = 1.00 ≤ C ≤ 1.10. Owner: 0 = national or provincial; 1 = regional. Contract amount: 0 = <$250,000; 1 = $250,000–$1 Million; 2 = >$1 Million.

Table 6. Logistic regression results with contract cost overrun as the dependent variable

Independent variable	B	Standard error	Wald	gl	Sig.	Exp (B)
Payment strategy: 0–1	0.598	0.258	5.395	1	0.020	1.819
Owner: 0–1	1.152	0.346	11.079	1	0.001	3.164
Contract amount	—	—	32.289	2	0.000	—
Contract amount: 0–1	1.039	0.292	12.667	1	0.000	2.827
Contract amount: 0–2	2.334	0.414	31.762	1	0.000	10.322

Note: B = regression coefficients; gl = degrees of freedom; Wald = Wald statistic; Exp (B) = log-odds of success; and Sig. = 2-tailed p-value (significant if <0.05). Payment strategy: 0 = Lump sum; 1: Unit prices. Owner: 0 = national or provincial; 1 = regional. Contract amount: 0 = <$250,000; 1 = $250,000–$1 Million; 2 = >$1 Million.

for the contract amount, an increasing trend is observed; the higher the contract amount, the greater the probability that the contract will be delayed. This probability is 30 times higher when the amount is greater than $ 1 million compared to a value of less than $ 250,000. On the other hand, when the contract is awarded with an award coefficient greater than or equal to 1, it is 0.5 times less likely to be delayed than when it is awarded with a coefficient of less than 1. As for the variable owner, when the owner is a regional administrator, the probability of the contract ending late is 2.8 times higher than when the owner is a national or provincial administrator.

Conversely, in relation to the variables influencing the occurrence of cost overruns, Table 6 shows the results of the logistic regression. The contract amount is the variable that most significantly influences the occurrence of cost overruns with a Wald value of 32.289, followed by the owner (Wald = 11.079) and the payment strategy (Wald = 5.395). With respect to the value of the Odds ratios (Exp (B)), the higher the contract value, the greater the probability that the contract will end with a cost overrun. This probability is 10 times higher when the budget is greater than $1 million compared to an amount of less than $250,000. As for the owner variable, when the owner is a regional administration, the probability of the contract ending with a cost overrun is 3 times higher than if the owner is a national or provincial administration. On the other hand, when the contract's payment strategy is unit prices, it is 1.8 times more likely to have a cost overrun than if a lump sum is used.

These results are consistent with previous research by Heravi and Mohammadian (2017) and Gómez-Cabrera et al. (2020), which found that smaller projects experience better cost and schedule performance. Choi et al. (2021) demonstrated a significant negative correlation between project size and cost performance but found no significant correlation between project size and schedule performance. On the other hand, Flyvbjerg et al. (2004) used a regression analysis for 258 transport infrastructure projects and found that cost overruns were highly dependent on project size.

When the contract is awarded with an award coefficient greater than or equal to 1, it is less likely to be delayed. Similarly, other authors conclude that awarding the project to the lowest bidder is one of the most important causes of delay (Mahamid et al. 2012; Santoso and Soeng 2016); and project cost overruns (Rosenfeld 2014). However, this significance in the occurrence of delay and not cost overruns may be because the economic factor is more sensitive in public projects in Peru. In Peru, the regulatory framework stipulates that cost overruns exceeding 15% of the initial contract amount require express authorization from the Controller General of the Republic, which is the public body in charge of controlling the effective, efficient, and transparent use of public resources. The lowest price is one of Peru's most frequent criteria for awarding public projects. The lowest bidders, however, in some cases are generally low-skilled, under-resourced, and have inadequate experience, resulting in poor project performance (Santoso and Soeng 2016). Therefore, it is necessary to improve the award policy to control this problem. In this line, several authors recommend improving the award criteria, giving less importance to price and more to contractors' capabilities and track record of past procurement performance (Odeh and Battaineh 2002; Santoso and Soeng 2016).

The likelihood that the contract will end with delays and cost overruns increases when it is a regional government. Alaghbari et al. (2007) found that the owner's ability to manage the project is an important factor causing delays in construction projects in Malaysia. On his part, Khan et al. (2021) revealed that project governance has a direct positive relationship with the performance of public projects. Previous studies in Peru (Lozano 2012) characterized regional governments as having inadequate planning, deficiencies in engineering studies, inability to manage, improvisation and haste in decision making, disorganization, and negligence in execution—all being aspects that hinder the efficient project execution of public projects, ultimately affecting deadlines, costs, and quality (Lozano 2012). Therefore, this result suggests that administrations with better project management practices achieve better project performance in terms of cost and time.

Finally, regarding the payment strategy, when the contract is executed on a unit price basis, there is a greater likelihood that the contract will end with a cost overrun for the administration. In this regard, the Peruvian regulatory framework stipulates that in lump sum contracts, the quantity and quality of the project are clearly defined in the construction project documents; therefore, it is understood that the risk of higher costs during execution is transferred to the contractor, while in unit price contracts the risk of cost increases is assumed by the public administration. Along these lines, Choi et al. (2021) highlighted that lump sum procurement is an effective option for delivering projects within budget.

Association between Delay and Cost Overrun

To analyze the degree of association between delay and cost overruns caused by each of the identified risks, a Pearson Chi-square test was carried out. This test assesses whether there is an association between the occurrence of impact on time and cost of the same risk and the degree of association. Table 7 shows the degree of association between the occurrence of delay and cost overruns for the 21 risks that showed an association, i.e., they had a significance value of less than 0.05, indicating that there is an association (Field 2009). The degree of association between the different risks is related to the likelihood that the occurrence of the risk will result

Table 7. Degree of association between delay and risk cost overruns

Risk	Phi	Association
R-27 COVID-19 state of emergency	1.000	Perfect
R-12 Inadequate methods for quality control and quality assurance	1.000	Perfect
R-8 Redesign due to changes in the original technical design	0.830	Very high
R-3 Changes in project scope	0.814	Very high
R-10 Inaccurate soil survey	0.767	High
R-13 Inaccurate site information	0.746	High
R-1 Delay in payment to a contractor	0.706	High
R-11 Errors and discrepancies in design documents	0.651	High
R-26 Unforeseen worksite conditions	0.621	High
R-19 Governmental permits	0.607	High
R-2 Land availability problems	0.597	Moderate
R-20 Regulatory changes	0.576	Moderate
R-17 Availability/authorization of utilities on site (water, electricity)	0.576	Moderate
R-18 Interruption of works from public entities	0.574	Moderate
R-5 Delay in responding to inquiries	0.568	Moderate
R-6 Administrative silence in response to requests from the contractor	0.532	Moderate
R-4 Delay in change order approvals	0.520	Moderate
R-16 Permission from the service provider to carry out work on existing building sites	0.495	Moderate
R-15 Claims from project users	0.465	Moderate
R-23 Adverse weather conditions	0.372	Low
R-9 Inaccurate cost estimates at the design stage	0.235	Low

in both project delays and cost overruns. The interpretation of phi values considers the five categories proposed by Sanz (2015) and Field (2009): perfect (1.0), very high (0.8–1.0), high (0.6–0.8), moderate (0.4–0.6), and low (0.2–0.4). The results show that, in the case of risks R-27_COVID state of emergency and R-12_Inadequate methods, for quality control and quality assurance, there exists a perfect association. This means that whenever these risks occur, they will lead to both delays and cost overruns. This perfect association is probably due to the increased overhead costs to the contractor as a consequence of delays. Risks R-8_Redesign due to changes in the original technical design and R-3_Changes in project scope have a very high association, and six additional risks (detailed in Table 7) have a high association. Monitoring risks with high levels of association is critical because they would impact the schedule and cost if they materialize.

Worldwide studies on delay and cost overrun risks in construction have studied delay and cost overrun risks independently. However, several authors point out that factors causing delay also lead to cost overruns (Bhargava et al. 2010; Kaliba et al. 2009; Sambasivan and Soon 2007). Some authors conclude that the relationship between delay and cost overrun factors in public projects is moderate (Alinaitwe et al. 2013). This research shows that the degree of association between cost and time depends on the type of risk.

When interpreting these results, it is important to clarify that the risks not listed in Table 7 are risks that when they materialized only caused an impact on time.

Conclusions

Findings in this study suggest that the risks for delays and cost overruns in Peru are aligned with the ones obtained by other authors worldwide. The novelty of this study is that, unlike previous studies that used retrospective opinions of the parties involved, this paper provides information on risks of delay and cost overruns based on empirical data. This study also found that, despite the Peruvian government having made substantial investments in the last few years in drinking water supply and sanitation projects, improving the performance of these projects is significantly hampered by delays and cost overruns.

Delays and cost overruns can be avoided or minimized when risks are identified early in the process. This research analyzes the main risks causing delays and cost overruns and determines those contracting characteristics that significantly influence the occurrence of delays and cost overruns in contracts.

Information was collected from 318 project contracts, such as documents by which extensions of time and cost overruns are granted to the contractor, as well as completion certificates and the contracting characteristics of the projects. The research method was based on content analysis, descriptive statistics, logistic regression analysis, and Chi-square. The results indicate that 39.9% of the contracts experienced neither delay nor cost overrun, 55.7% had delays, and 44.7% had cost overruns. Also, the risks associated with the owner category have the greatest impact on time; however, the risks associated with the consultant have the greatest impact on cost.

Regarding the main risks, descriptive statistics demonstrate that, in terms of frequency of occurrence, the most important risks are: delay in change order approvals; adverse weather conditions; inaccurate site information; inaccurate cost estimates at the design stage, and land availability problems. From these risks, delays in change order approvals; adverse weather conditions, and land availability problems play an important role in the occurrence of delays, while inaccurate site information and inaccurate cost estimates at the design stage influence the occurrence of cost overruns.

Our analysis also found that the contract amount is the variable that most significantly influences the occurrence of delay and cost overruns. The higher the contract value, the greater the probability that the contract will end with delay and cost overruns. The type of owner is another variable that influences the occurrence of delay and cost overruns: when the owner is a regional administration, the probability that the contract will end with delay and cost overruns increases (when compared to local and national owners). On the other hand, the low award influences the occurrence of delay, and when the contract is awarded with a coefficient greater than or equal to 1, there is less probability of delay. Finally, the payment strategy influences the occurrence of cost overruns, and when the contract is executed at unit prices, there is a greater probability that the contract will end with a cost overrun for the administration when compared to a lump sum, where this risk is transferred to the contractor.

Results of this study also show that the degree of association between cost overruns and delays also depends on the type of risk. The risks COVID-19 state of emergency, inadequate methods for quality control and quality assurance, redesign due to changes in the original technical design, changes in project scope, inaccurate soil survey, inaccurate site information, delay in payment to contractor, errors and discrepancies in design documents, unforeseen worksite conditions, and government permits showed high to perfect levels of association in terms of delay and cost overruns.

The proposed logistic regression models can serve as a tool in the planning phase to identify contracts most likely to have delays and cost overruns based on their procurement characteristics.

The findings of this research in Peru offer valuable insights into the primary risks associated with delays and cost overruns, as well as the impact of contracting characteristics on project outcomes. These results serve to enhance the understanding of project management professionals regarding the key challenges encountered in the efficient execution of drinking water supply and sanitation projects in Peru. Such insights are beneficial not only for public administrations but also for contractors involved in public projects.

Although these findings cannot be directly extrapolated to other locations, they provide valuable insights to inform enhancements in the procurement and construction processes in other countries.

Limitations

The data collection process relied on documents available on the InfObras website. However, it was observed that many of the projects lacked essential information, rendering them unsuitable for inclusion in the research sample. Consequently, the sample selection had to prioritize contracts with complete information, leading to a deviation from a truly random sample. Another limitation arose from the identification of risks attributed to the contractor. Since the primary data source was change order documentation, which typically entails the extension of deadlines or additional costs borne by the contractor, this study's scope was confined by the Peruvian regulatory framework. According to these regulations, contractors are only eligible for such modifications in cases where they are not responsible for the underlying risk.

Another limitation is that the linear regression analysis was performed with the variables described in Table 2. However, other variables such as contractor and project characteristics/scope may significantly influence the occurrence of delay and cost overruns in the projects, which may be the reason for analysis in future research.

Future Research

A future line of research should analyze risks in terms of probability of occurrence and impact. Additionally, exploring other variables, such as the characteristics of consulting firms and contractors, would provide valuable insights into their role delays and cost overruns. Extending this research approach to include other critical infrastructure, such as schools, hospitals, and roads, would contribute to a broader understanding of project management challenges. It would also be very important to analyze the main mitigation measures that can be established to reduce their impact and probability of occurrence. Another future research would be to analyze those contracting characteristics that significantly influence the occurrence of each of the delay and cost overrun risks identified in this study.

Data Availability Statement

Some or all data, models, or code generated or used during the study are available from the corresponding author by request.

Acknowledgments

The authors acknowledge the financial support of the Valencian Regional Government through the Conselleria de Educación, Universidades y Empleo (Education, Universities and Employment Agency) (Project CIAICO/2023/216). Furthermore, the valuable commentaries and suggestions of three anonymous reviewers are highly appreciated.

Supplemental Materials

Examples of the risks identified in the change orders documents and Table S1 are available online in the ASCE Library (www.ascelibrary.org).

References

Abd El-Razek, M. E., H. A. Bassioni, and A. M. Mobarak. 2008. "Causes of delay in building construction projects in Egypt." *J. Constr. Eng. Manage.* 134 (11): 831–841. https://doi.org/10.1061/(ASCE)0733-9364(2008)134:11(831).

Ahmed, M. O., and I. H. El-adaway. 2023. "Data-driven analysis of construction bidding stage–related causes of disputes." *J. Manage. Eng.* 39 (5): 04023026. https://doi.org/10.1061/JMENEA.MEENG-5426.

Alaghbari, W., M. R. A. Kadir, A. Salim, and Ernawati. 2007. "The significant factors causing delay of building construction projects in Malaysia." *Eng. Constr. Archit. Manage.* 14 (2): 192–206. https://doi.org/10.1108/09699980710731308.

Al-Hazim, N., and Z. Abusalem. 2015. "Delay and cost overrun in road construction projects in Jordan." *Int. J. Eng. Technol.* 4 (2): 288. https://doi.org/10.14419/ijet.v4i2.4409.

Alinaitwe, H., R. Apolot, and D. Tindiwensi. 2013. "Investigation into the Causes of Delays and Cost Overruns in Uganda's Public Sector Construction Projects." *J. Constr. Dev. Countries* 18 (2): 33–47.

Al-Momani, A. H. 2000. "Construction delay: A quantitative analysis." *Int. J. Project Manage.* 18 (1): 51–59. https://doi.org/10.1016/S0263-7863(98)00060-X.

Awwad, R., and Z. Thabet. 2024. "Effect of implementing sustainable management practices on construction claim mitigation." *J. Manage. Eng.* 40 (1): 04023065. https://doi.org/10.1061/JMENEA.MEENG-5552.

Bagaya, O., and J. Song. 2016. "Empirical study of factors influencing schedule delays of public construction projects in Burkina Faso." *J. Manage. Eng.* 32 (5): 05016014. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000443.

Bhargava, A., P. C. Anastasopoulos, S. Labi, K. C. Sinha, and F. L. Mannering. 2010. "Three-stage least-squares analysis of time and cost overruns in construction contracts." *J. Constr. Eng. Manage.* 136 (11): 1207–1218. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000225.

Chapman, R. J. 2001. "The controlling influences on effective risk identification and assessment for construction design management." *Int. J. Project Manage.* 19 (3): 147–160. https://doi.org/10.1016/S0263-7863(99)00070-8.

Choi, K., Y. Yin, D. Goehl, and H. D. Jeong. 2021. "Alternative contracting methods: Modeling and assessing the effects of contract type on time-cost-change performance." *J. Manage. Eng.* 37 (1): 04020096. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000863.

Cohen, J. 1960. "A coefficient of agreement for nominal scales." *Educ. Psychol. Meas.* 20 (1): 37–46. https://doi.org/10.1177/001316446002000104.

Controller General of the Republic. 2019. "Report on paralyzed works 2019." Accessed March 30, 2019. https://www.gob.pe/institucion/contraloria/informes-publicaciones/1635195-reportes-de-obras-paralizadas.

Controller General of the Republic. 2021. "Public works information system." Accessed April 19, 2021. https://infobras.contraloria.gob.pe/infobrasweb.

Controller General of the Republic. 2024. "Report of paralyzed works in the national territory as of March 2024." Accessed May 3, 2024. https://www.gob.pe/institucion/contraloria/informes-publicaciones/5522683-informe-de-obras-paralizadas-en-el-territorio-nacional-a-marzo-2024.

Derakhshanfar, H., J. J. Ochoa, K. Kirytopoulos, W. Mayer, and V. W. Y. Tam. 2019. "Construction delay risk taxonomy, associations and regional contexts: A systematic review and meta-analysis." *Eng. Constr. Archit. Manage.* 26 (10): 2364–2388. https://doi.org/10.1108/ECAM-07-2018-0307.

Elbashbishy, T. S., O. A. Hosny, A. F. Waly, and E. M. Dorra. 2022. "Assessing the impact of construction risks on cost overruns: A risk path simulation-driven approach." *J. Manage. Eng.* 38 (6): 04022058. https://doi.org/10.1061/(ASCE)ME.1943-5479.0001090.

Elinwa, A. U., and M. Joshua. 2001. "Time-overrun factors in Nigerian construction industry." *J. Constr. Eng. Manage.* 127 (5): 419–425. https://doi.org/10.1061/(ASCE)0733-9364(2001)127:5(419).

El-Sayegh, S. M., and M. H. Mansour. 2015. "Risk assessment and allocation in highway construction projects in the UAE." *J. Manage. Eng.* 31 (6): 04015004. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000365.

Faridi, A. S., and S. M. El-Sayegh. 2006. "Significant factors causing delay in the UAE construction industry." *Construct. Manage. Econ.* 24 (11): 1167–1176. https://doi.org/10.1080/01446190600827033.

Fewtrell, L., and J. M. Colford. 2005. "Water, sanitation and hygiene in developing countries: Interventions and diarrhea: A review." *Water Sci. Technol.* 52 (8): 133–142. https://doi.org/10.2166/wst.2005.0244.

Feyzbakhsh, S., A. Telvari, and A. R. Lork. 2018. "Investigating the causes of delay in construction of urban water supply and wastewater project in water and wastewater project in Tehran." *Civ. Eng. J.* 3 (12): 1288. https://doi.org/10.28991/cej-030958.

Field, A. 2009. *Discovering statistics using SPSS*. 3rd ed. London: SAGE.

Flyvbjerg, B., M. S. Holm, and S. Bulh. 2002. "Underestimating costs in public works projects: Error or lie?" *J. Am. Plann. Assoc.* 68 (3): 279–295. https://doi.org/10.1080/01944360208976273.

Flyvbjerg, B., M. K. Skamris Holm, and S. L. Buhl. 2004. "What causes cost overrun in transport infrastructure projects?" *Transp. Rev.* 24 (1): 3–18. https://doi.org/10.1080/0144164032000080494a.

Frimpong, Y., J. Oluwoye, and L. Crawford. 2003. "Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study." *Int. J. Project Manage.* 21 (5): 321–326. https://doi.org/10.1016/S0263-7863(02)00055-8.

Gómez-Cabrera, A., A. Sanz-Benlloch, L. Montalban-Domingo, J. L. Ponz-Tienda, and E. Pellicer. 2020. "Identification of factors affecting the performance of rural road projects in Colombia." *Sustainability* 12 (18): 7377. https://doi.org/10.3390/su12187377.

Gündüz, M., Y. Nielsen, and M. Özdemir. 2013. "Quantification of delay factors using the relative importance index method for construction projects in Turkey." *J. Manage. Eng.* 29 (2): 133–139. https://doi.org/10.1061/(asce)me.1943-5479.0000129.

Hamzaoui, F., F. Taillandier, R. Mehdizadeh, D. Breysse, and A. Allal. 2015. "Evolutive Risk Breakdown Structure for managing construction project risks: Application to a railway project in Algeria." *Eur. J. Environ. Civ. Eng.* 19 (2): 238–262. https://doi.org/10.1080/19648189.2014.939416.

Heravi, G., and M. Mohammadian. 2017. "Cost overruns and delay in municipal construction projects in developing countries." *AUT J. Civ. Eng.* 1 (1): 31–38. https://doi.org/10.22060/ceej.2017.12189.5163.

Huo, T., H. Ren, W. Cai, G. Q. Shen, B. Liu, M. Zhu, and H. Wu. 2018. "Measurement and dependence analysis of cost overruns in megatransport infrastructure projects: Case study in Hong Kong." *J. Constr. Eng. Manage.* 144 (3): 05018001. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001444.

Hutton, G. 2013. "Global costs and benefits of reaching universal coverage of sanitation and drinking-water supply." *J. Water Health* 11 (1): 1–12. https://doi.org/10.2166/wh.2012.105.

Hutton, G., L. Haller, and J. Bartram. 2007. "Global cost-benefit analysis of water supply and sanitation interventions." *J. Water Health* 5 (4): 481–502. https://doi.org/10.2166/wh.2007.009.

Johnson, R. M., and R. I. I. Babu. 2020. "Time and cost overruns in the UAE construction industry: A critical analysis." *Int. J. Constr. Manage.* 20 (5): 402–411. https://doi.org/10.1080/15623599.2018.1484864.

Kaliba, C., M. Muya, and K. Mumba. 2009. "Cost escalation and schedule delays in road construction projects in Zambia." *Int. J. Project Manage.* 27 (5): 522–531. https://doi.org/10.1016/j.ijproman.2008.07.003.

Khan, A., M. Waris, S. Panigrahi, M. R. Sajid, and F. Rana. 2021. "Improving the performance of public sector infrastructure projects: Role of project governance and stakeholder management." *J. Manage. Eng.* 37 (2): 04020112. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000886.

Koo, H. J., and J. T. O'Connor. 2021. "Complexity analysis of design deliverable defects on building projects." *J. Manage. Eng.* 37 (3): 04021014. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000897.

Krippendorff, K. 2004. *Content analysis: An introduction to its methodology.* Los Angeles: SAGE.

Larsen, J. K., G. Q. Shen, S. M. Lindhard, and T. D. Brunoe. 2016. "Factors affecting schedule delay, cost overrun, and quality level in public construction projects." *J. Manage. Eng.* 32 (1): 04015032. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000391.

Liu, J., Q. Xie, B. Xia, and A. J. Bridge. 2017. "Impact of design risk on the performance of design-build projects." *J. Constr. Eng. Manage.* 143 (6): 04017010. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001299.

Lozano, E. 2012. "Efficiency in the execution of public works: A pending task on the road to regional competitivity: A governmental control approach." *Revista TCEMG* 112–129.

Mahamid, I., A. Bruland, and N. Dmaidi. 2012. "Causes of delay in road construction projects." *J. Manage. Eng.* 28 (3): 300–310. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000096.

Ministry of Housing Construction and Sanitation. 2021. "National Sanitation Plan 2022–2026." Accessed December 24, 2021. https://www.gob.pe/institucion/vivienda/informes-publicaciones/2586305-plan-nacional-de-saneamiento-2022-2026.

Montalbán-Domingo, L., T. García-Segura, M. Amalia Sanz, and E. Pellicer. 2019. "Social sustainability in delivery and procurement of public construction contracts." *J. Manage. Eng.* 35 (2): 04018065. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000674.

Neuendorf, K. A. 2017. *The content analysis guidebook*. Thousand Oaks, CA: SAGE.

Odeck, J. 2004. "Cost overruns in road construction—What are their sizes and determinants?" *Transp. Policy* 11 (1): 43–53. https://doi.org/10.1016/S0967-070X(03)00017-9.

Odeh, A. M., and H. T. Battaineh. 2002. "Causes of construction delay: Traditional contracts." *Int. J. Project Manage.* 20 (1): 67–73. https://doi.org/10.1016/S0263-7863(00)00037-5.

Perrenoud, A. J., J. B. Smithwick, K. C. Hurtado, and K. T. Sullivan. 2016. "Project risk distribution during the construction phase of small building projects." *J. Manage. Eng.* 32 (3): 04015050. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000417.

Rosenfeld, Y. 2014. "Root-cause analysis of construction-cost overruns." *J. Constr. Eng. Manage.* 140 (1): 04013039. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000789.

Ruqaishi, M., and H. A. Bashir. 2014. "Causes of delay in construction projects in the oil and gas industry in the Gulf Cooperation Council countries: A case study." *J. Manage. Eng.* 31 (3): 05014017. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000248.

Sambasivan, M., and Y. W. Soon. 2007. "Causes and effects of delays in Malaysian construction industry." *Int. J. Project Manage.* 25 (5): 517–526. https://doi.org/10.1016/j.ijproman.2006.11.007.

Santoso, D. S., and S. Soeng. 2016. "Analyzing delays of road construction projects in Cambodia: Causes and effects." *J. Manage. Eng.* 32 (6): 05016020. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000467.

Sanz, A. 2015. *Influence of collaborative behaviour in the construction of privately developed residential buildings in Spain. Comparison with the North American experience*. Valencia, Spain: Univ. Polytechnic of Valencia.

Shane, J. S., K. R. Molenaar, S. Anderson, and C. Schexnayder. 2009. "Construction project cost escalation factors." *J. Manage. Eng.* 25 (4): 221–229. https://doi.org/10.1061/(ASCE)0742-597X(2009)25:4(221).

Siraj, N. B., and A. R. Fayek. 2019. "Risk identification and common risks in construction: Literature review and content analysis." *J. Constr. Eng. Manage.* 145 (9): 03119004. https://doi.org/10.1061/(ASCE)CO.1943-7862.0001685.

Stanford, M. S., K. R. Molenaar, and K. M. Sheeran. 2016. "Application of indefinite delivery–indefinite quantity construction strategies at the federal level." *J. Manage. Eng.* 32 (5): 04016011. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000437.

Vivanco, M. 2005. *Statistical sampling design and applications*. Santiago de Chile: Editorial Universitaria SA.

World Competitiveness Center. 2024. "IMD World Competitiveness Booklet 2024." Accessed November 2, 2024. https://www.imd.org/centers/wcc/world-competitiveness-center/rankings/world-competitiveness-ranking/.