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Risk Evaluation of Cost Overruns (COs) in Public Sector Construction Projects: A Fuzzy Synthetic Evaluation

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Abstract: In the Small Island Developing States (SIDS), public sector infrastructure projects (PSIPs) fail to both meet targeted performance metrics and deliver on the intended benefits to society. In terms of the cost performance metric, cost overruns (COs) beyond the initial contract value are more of a norm than a unique occurrence. Therefore, to ensure economic sustainability for SIDS, and value for money on PSIPs, there is a need to investigate and evaluate the risk impacts on COs. The purpose of this research was to identify and evaluate the perceived cost overrun risk factors that are within the primary project stakeholders' sphere of control, and to reduce the ongoing ambiguities that exist in the prioritization of these risks. This was achieved by extracting critical risk factors from selected comparative studies in developing countries to formulate a closed-ended questionnaire to be administered to construction professionals in Trinidad and Tobago. Thereafter, the process of fuzzy synthetic evaluation (FSE) was used to develop a risk model based on three tiers of risks: 11 critical risk factors, 3 critical risk groupings (CRGs) and an overall risk level (ORL). The results showed that the two highest-ranked critical risks were project funding problems and variations by client. The leading critical risk grouping was client-related risk (5.370), followed by professional-related risk (4.815) and physical risk (4.870). The ORL was 5.068. Based on the FSE's linguistic scaling, the CRGs and the ORL are perceived to be high risks in PSIPs. This research adds to the CO body of knowledge in primarily three ways. Firstly, the study extends the comparative assessment previously undertaken in scholarship into the context of SIDS to build on the generalizability of this context-specific phenomenon. Secondly, the FSE evaluation undertaken provides a practical tool to be promoted for use in SIDS' construction industry among practitioners to focus and prioritize the critical risks in the planning phases and improve on contemporary risk practices in the execution phases of projects. Finally, this quantitative model approach is recommended to supplement the traditional qualitative risk management practices adopted in SIDS, thus contributing towards the overall improved economic sustainability and viability of PSIPs.

Keywords: risk impacts; cost overrun (COs); public sector; contracts; fuzzy model; construction

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1. Introduction

Accurate cost forecasting is a major problem in any construction project. The ongoing debates in scholarship have proven one fact: little progress has been made around the continent in curbing cost overruns (COs). Leading scholarship showed that 9 out of 10 major projects witnessed overruns of 50% to 100% [1] and identified COs as the primary issue affecting project success. There are other detrimental causalities when costs are misappropriated, such as delays until more funding is both identified and obtained by the client, and reductions in profit margins suffered by the contractor. In the case of public sector projects in Small Island Developing States (SIDS), COs on a large infrastructure project affect the economic sustainability of the particular island nation and diminish planned progress in future infrastructural initiatives [2]. Hence, the minimization of COs is essential for any construction project to perform successfully. Through informed mitigation strategies, the prevention of COs can lead to an overall improved client–contractor relationship, increased profitability of the project and an increase in development in public sector projects [3].

Thus, the project team is constantly challenged to develop effective strategies to reduce the likelihood of COs. Scholarship in COs has shown the dominance of the factor school of thought, discussing the nature and types of risks, success and failure factors and the root causes influencing these factors [3]; from the perspective of root causes and team dynamism, there are controllable root causes, which are technical and psychological in nature, where the team can recognize issues, reflect and strategize and implement contingencies to quickly reduce any potential limitations. There are also uncontrollable root causes, which are political and socio-economic in their nature, and require contingencies and dependencies external to the team's sphere of control. Chadee et al. [1] demonstrated the pervasive nature and dominance of political influences within public housing programs in SIDS, where the outcome is cost overruns averaging 85%, which directly limits the forecasted supply and quality of this public good. However, this study re-directs the mitigative approach to controllable root causes and, more fundamentally, builds on the comparison and evaluation of associated critical risk factors (CRFs) found to influence both developing and developed nations. This was achieved by considering the critical success factors responsible for the successful performance of construction projects found in prior research conducted by Osei-Kyei et al. [4]. Through factor analysis, the critical success groups for infrastructure projects were delivery of service, sufficient legal structures, the simple structure of payment along with the project being consistently monitored and effective contract management.

Though obviously stated, a simple payment mechanism is a critical success factor group leading to fewer contractor cost-related issues, and consistent project monitoring allows for the detection of potential cost hazards before they occur. An example of a simplified payment method would be in the procurement methods of target cost contracts and guaranteed maximum price contracts stated in the United Kingdom and Australia [5]. The problem of COs, however, does not necessarily occur during the construction process but can be a result of resource constraints at the beginning of the project [6]. This often results in variations to the contract sum, and a contributor to COs. A CO cycle is then created when a contract is awarded to the lowest-bidding contractor, who in turn relies on the award of variation monies during the construction phase to continue and complete the project [2]. The CO cycle is an ongoing issue and presents a serious debate in the construction industry because the initial budgets infrequently account for the main cost overrun risk factors. This leads to risky and unsustainable infrastructure projects.

Risk, defined as the product of the likelihood or probability of an event/hazard occurring by the severity or impact of such event/hazard occurring [3], is typically captured by the project team using risk registers under a qualitative risk assessment matrix. This form of risk capturing and assessment is left to an individual's subjective assessment, and consequently leads to imprecision in risk prioritization and decision making. This further results in the misallocation of limited project resources, and consequential ineffective mitigation strategies. A major problem in these public sector projects is the capturing of accurate data to evaluate risks, and the access to data from project to project [3,4]. Since the available knowledge on risk evaluation is shrouded in imprecision and vagueness, a better understanding of CO risk factors is needed. Thus, to add to this knowledge area, this study aims to identify and evaluate perceived controllable cost overrun risk factors affecting the successful performance of construction projects. To achieve this aim, three main objectives are proposed. The first objective is to develop a comparison of CRFs in the context of SIDS and other developing economies to understand any variability in risk based on varying geographies and economies. The second objective is to acquire the relevant perception data from various construction professionals in Trinidad and Tobago, a Caribbean SIDS, through a closed-ended questionnaire tool. These data are then processed to develop a fuzzy synthetic evaluation (FSE) model, which provides an empirical ranking of the established critical risk groupings and risk levels of the CRFs. The final objective is to provide recommendations to mitigate these critical factors for the project team undertaking public sector construction projects.

Due to the context-dependent nature of COs [3], this study moves one step closer towards generalizability with the inclusion of SIDS into the discourse through the undertaking of a comparative assessment with scholarship [4]. On a niche scale, the proposed FSE model provides much needed empirical data to both project practitioners and academia for the evaluation of critical risks, associated risk groupings and the overall risk level significantly affecting the variability of contract sums. This model also provides a visual structure for policy makers and decision makers to observe risks, not as individual attributes but rather as a multi-tiered, causally linked hierarchy, where a holistic treatment is prescribed to supplement contemporary qualitative risk mitigation strategies.

2. Theoretical Background

Construction projects have become increasingly complex in terms of both design and execution [1]. The increased level of complexity exposes the vulnerabilities of projects and gives rise to the prominence of a multiplicity of risk factors. These risks, if not properly managed, are left ignored and adversely impact the project's scope and intended objectives and ultimately hinder project success [5]. Risk factors and their respective impacts are known to be directly related to COs, leading some scholars to conclude that cost and risk are possibly the most significant factors involved in decision making for many scenarios [7].

The success or failure of public sector infrastructure projects is characterised by risk factors that significantly impact the variability between the contract sum and final account [6,7]. The risk factors influencing variability in contract sums are not limited to specific economies globally and affect both developed and emerging economies. Therefore, contingencies such as geographies and economies have given rise to the context specificity of the CO phenomenon [3,4]. It is also shown that sectoral growth in construction initiatives is limited in developing economies due to limitations in resources, competence and adaptability to modern and advanced construction techniques compared to those in developed economies [8,9]. Prior research done by Ngowi et al. [9] stated a significant financing deficit in public infrastructure in developing nations, due to globalization's inability to deliver the necessary capital. This falls under the category of funding problems by the government, which is classified as a public client. For public clients, however, the variation in contract sums stems from the procurement stage. Mansfield, Ugwu et al. [10] and Odeyinka and Perera [11] expressed the view that in terms of bid sums, public sector building projects frequently exceed their initial budgets. Likewise, Kaming and Olomolaiye [12] shared a similar view in stating that the original estimate for a project during the pre-contract stage typically becomes the proposed bidding amount, and public clients do not anticipate this estimate to be surpassed. A historical account of public projects, however, paints a different picture—that is, final contract sums rarely fall within the estimate [1]. In the case of Ghana, public clients must work within constrained predetermined budgets, which becomes a major challenge when the contract sum is exceeded due to insufficient and inaccurate cost forecasting during the pre-contract stage, or other factors such as material price increases, inflationary pressures and government actions, among others [13,14].

Under conventional procurement arrangements, separate parties try to accomplish their own specific project objectives rather than the overall project objectives, which can lead to unwanted difficulties such as adversarial working relationships between contracting parties [5]. From contractual theory, working relationships are related to the terms and conditions of a contract, which calls for the careful review and alignment of the procurement strategy, route and type to the complexity of the project and the intended relationship to procure. A study by Chan et al. [5] investigated the risk factors of construction projects procured with target cost contracts (TCC) and guaranteed maximum price contracts (GMPC). A TCC provides an estimation of the cost of the scope of work and the initial target cost is adjusted as construction work advances. Adjustments in costs are known through prior agreement between the client or the nominated representative and the contractor to account for any changes to the original scope and specifications. On the other hand, the GMPC restricts the proposed tendered sum as the set maximum price—that is, this type of contract is a cost guarantee that the final cost of the project will not exceed the maximum price [5]. In the case of any variation in the contract sum with respect to the final account, the difference would be shared between the employer and the contractor based on a pre-determined share ratio as stated in the contract and the contractor is paid the actual cost for the work done during the construction stage [15], which reduces the contractual risk [5,6].

Another method to control and measure work progress is the use of Bills of Quantities (BOQs). The BOQs, based on a bottom-up approach to estimation and being effective representations to track scope and measure valued works, are traditionally used in procurement strategies where the public client undertakes the delivery of complete designs prior to tendering. However, project estimates based on BOQs are also a major reason for variations in contract sums [16]. The inaccuracy in cost estimation that leads to variations in pre-tender sums can be identified by two factors [13], mainly incomplete plans and specifications during quantity surveying and the client's estimators' use of unsatisfactory unit pricing analysis data. In most developing countries, the lowest bid model is the main model used in obtaining bids. The strategy employed in this model is to compare the verified submitted tenderers' sums to an engineer's estimate of the project. If a contractor bid amount falls within the prescribe range of the engineer's estimate, then it is classified as valid. However, some government agencies request from the contractor a justification for their low tender. Depending on the influence of the contractor, the value of engineering offered and the quality of the contractor's justifications, the award of the construction contract may lean towards this preferred contractor [2,3]. In the absence of other risk considerations, the lowest bidder award creates the perception by the client that the cost is being minimized, and value for money is derived. In most instances, other associated CO risks are ignored, either deliberately or by genuine oversight, resulting in a riskier project with a smaller budget as opposed to if the contract was awarded based on a realistic cost. This phenomenon was expressed by Mahamid et al. [17] in the Gaza Strip, who identified the awarding of projects according to the lowest bid price to be a major risk factor. Therefore, BOQ models are not an accurate method of determining project costs, and this was concluded to be the top risk factor leading to COs [18].

When investigating the risk factors for variations in contract sums, which subsequently lead to COs, the interconnectivity of indirect factors, influencing the iron triangle success metrics of cost, quality and schedule [8], should not be ignored by practitioners. For example, considering the relationship between cost and schedule, it can be shown that factors causing delays in a project are also associated with the factors causing COs [17]. This gives support to the well-known statement that "time is money". Most construction projects experience delays; the magnitude of the delay experienced is project-dependent and risk variables that cause delays require ongoing identification in order to reduce, alleviate and eliminate them in each construction project [19]. This can be exemplified in the developing nation of Malaysia, where financial challenges, economic issues, material shortages, poor site management, construction errors and defective work and a consultant's lack of knowledge were several of the major factors leading to project delays [20]. These factors were also found to be linked to variations in contract sums and COs [10]. Poor finance and payment arrangements, usually a client-related risk, are found to be a critical factor limiting progress payments [21]. Ultimately, the successful completion of work shifts beyond the planned schedule from delayed payments and the consequential poor financial status of the project, again leading to delays and COs. Similarly, in Jordan, financial difficulties faced by contractors, together with too many change orders by the owner, are the major causes of construction delays [22]. These delay factors correspond to the CO factors "project funding problems and variations by clients" determined by Ameyaw et al. [6].

Closely related and correlated to funding problems is when clients frequently modify project designs throughout the building process without due care and consideration of budgetary limits. Design variations may be a necessity to accommodate numerous considerations, such as changing weather, consumer demands, latest technologies and green initiatives [18], among others. These variations, though important, negatively affect contractors' plans and may require substantial redesign [23], further contributing to additional costs and delays. The mitigation measures for construction delays can also be linked to CO control based on the established causal relationship between these factors [24]. The development and maintenance of planning initiatives, coordinating, controlling, organizing and motivating program resources and project components, are some general measures proposed to curb delays and COs. Even in the design stages, the impact of elemental designs and constructability should be viewed from a wholistic perspective to capitalize on cost synergies among various elements, including architectural, services, sustainability and maintenance. In reality, however, mitigation measures are rendered inefficient if the design is not considered from a wholistic perspective [25]. At times, it is left to the designers to make assumptions, decisions and choices about the projects' philosophy and outcomes. This can originate from inadequate project briefs providing incomplete information to the designers, resulting in a poor understanding of clients' requirements and poor assumptions [26], ultimately manifesting in design changes throughout various phases in the project with associated cost increases.

Public social infrastructure projects (PSIPs) in SIDS also experience similar CO risks. In Trinidad and Tobago, during the period 2005 to 2015, public housing had overrun its program estimate by TTD 2.4 billion, or a 50% average CO [2]. The period 2005 to 2010 saw an average of 85% CO. However, the period 2010 to 2015 showed a substantial reduction in CO, only averaging approximately 1%. The success was attributed to a change in competence, leadership and the identification of the primary root causes of CO, i.e., political and technical risks [3]. Technical risks are within the project team's sphere of control, whereas political risks were found to be the catalyst for technical inefficiencies [2]. However, an understanding of the technical risks' impact is required to control the cost outflows on the project. Most of the technical risk factors for PSIPs [2,3] were comparative to works by Ameyaw et al. [6], which, through the risk quantification method, produced risk factors such as project funding issues, underestimation of quantities, client variations, varied scope of work, inadequacy of specifications, design changes by the client, errors in designs and unexpected site conditions. Another CRF, a lack of statutory approval and delays in the issuance of project documents [18], is also noted in green projects in Singapore. To eliminate unnecessary delays, it was recommended that the approval process should be streamlined to allow variations, especially for larger ones to be fast-tracked, since unnecessary delays and excessive bureaucracy could affect the project parties' commitment to the project [4].

Other overlapping risk factors typically encountered in the Caribbean Islands are the variability in geological and soil conditions or geotechnical-related risks [6]. Smaller local contractors lack adequate capacity—that is, in terms of financial and technical capacity—to carry out proper soil and geotechnical investigations at the pre-contract stage of the project. Sun and Meng [26] rationalize that the site or ground conditions determine the design availability and when "abnormal ground conditions" are ignored, the probability of designs being ineffective is high. Furthermore, the issue of resource availability in SIDS cannot be overlooked. Material shortages and the fluctuations in material prices are commonly experienced on projects. Since SIDS do not benefit from economies of scale in manufacturing, most construction materials are imported and are subjected to further duties and taxation. This issue was identified as a high-impact risk factor that can be detrimental to the budget of a construction project. For example, as outlined in prior research done in Nigeria by Mansfield et al. [10], material shortages and general price fluctuations are leading factors influencing the variability in pre-tender sums and final accounts. Further validation was provided by Dlakwa and Culpin [27], who uncovered that plant, labor costs and material fluctuations are the main risk factors that can contribute to variations in contract sums. In the context of Turkey's construction industry, Arditi et al. [13] investigated COs in the public construction sector and also concluded that material prices and labor pay are on the rise, and obtaining materials at current official pricing is becoming more challenging. The COVID-19 pandemic was another major unforeseen, uncontrollable and unavoidable risk event that brought the world to a standstill between 2020 and 2022 [28]. The resumption in construction activities after this initial force majeure event saw material prices drastically rise in the SIDS [28]. It is important to note, however, that, collectively, these four studies also identified other similar risk factors that are responsible for variations in contract sums, inclusive of delayed payments by clients to contractors, poor payment arrangements, poor contract management, poor estimations of project costs and construction delays [29].

The characteristics of the building materials, for example, during the specification and selection of materials, sustainability, degradation processes, service life and maintainability, are also important considerations according to a previous study [30], since, in developing countries, there is a scarcity in financial resources and procuring substandard materials leads to associated quality and further financial outlays. It was observed that in Kuwait, a developed country with a high-income economy, growth in the variability in the contract sums resulted from material-related problems, client financial limitations and contractor-related problems [31]. Similarly, in Indonesia, which is classified as a developing/emerging lower-middle-income economy, the CO risk factors were determined to be related to poor material estimations, project complexity and inflationary influences on material costs [12]. Kaming's findings [12] are still applicable to this research as the Indonesian economy is still referred to as developing and the findings correlate to similar risk factors that were found in more recent studies by Ameyaw et al. [6]. The general trend across these studies is that variations in contract sums are a result of material price fluctuations, errors in estimation and the financial limitations of the client.

Another solution in understanding COs and how the associated risk factors can affect the successful performance of a construction project is to shift the current perspective to review critical success factors, as the success factors and risk factors of construction projects are inversely linked. In other words, the critical success factors are ignored or low, and CRFs are more likely to have a higher impact on the project. Osei-Kyei et al. [4] identified the critical success factors for public–private infrastructure projects (PPP) to be a result of effective procurement, project implementation, government guarantees, favorable economic conditions and the available financial market. In the initial stages of a PPP, project alignment with government strategic objectives is a major success factor. Critical success factors in PPPs were also investigated in Hong Kong [32] and Malaysia [33], respectively, and the results complemented those of Osei-Kyei et al. [4], which were transparent and efficient procurement process, good governance, a favorable legal framework, stable macroeconomic conditions, shared responsibility between public and private sectors and a sound economic policy. From these studies, it can be observed that there is a correlation between these critical success factors and the risk factors mentioned. To elaborate, a stable economic environment coupled with the public organizations' use of transparent procurement strategies can minimize contractual risk factors such as fluctuations in material prices. Furthermore, and of even greater importance, Chan et al. [5] suggested that having stringent health and safety policies and precautions in place is an objective indicator of project success. Injuries and loss of life on a construction site are not an occurrence of the past, and when such unfortunate situations occur, the project can be delayed or even suspended until all investigations are completed, which leads to severe additional COs. Evidence in support of this is found in research done by Zhao et al. [18] in Singapore's green projects, which concluded that workers in green projects face new high-risk tasks such as exposure to harmful substances and eyestrain. Thus, to protect against potential risks, the presence of these critical success factors can also be considered mitigation measures that decrease the likelihood of COs occurring by lessening the severity of the associated risk factors occurring, and ultimately lead to a successful construction project.

While CO studies are prevalent in the literature, the context-specific nature of this phenomenon [28] and the ideological divide surrounding CO episteme creates a gap towards knowledge convergence and theoretical generalizations [34]. Therefore, exploring and comparing the occurrence of the CO phenomenon in varying geographic contexts but similar economic classifications creates valuable insights into the growing body of knowledge in this specialist area, and narrows the ideological divide toward theoretical generalizations. For comparative purposes, similar reoccurring risk factors will form the basis of the risk assessment of the questionnaire and analysis of the research, as seen in Table 1. The success factors affecting the successful performance of construction projects were also a significant aspect of the literature, as an emphasis on these success factors would aid in developing mitigation methods for the risk factors. Therefore, to address the first objective proposed in this study, i.e., the development of a comparative CRF assessment for the context of SIDS, the first research question is proposed:

Table 1. Table showing established risk groupings and their respective risk factors for FSE.

Risk Groups (RGs)	Risk Factors (RFs)
RG1—Professional-Related Risks	1. Underestimation of Quantities 2. Change in Scope of Works 3. Change in Design by Architect 4. Defects in Design 5. Inadequate Specification 6. Third-Party Delays 7. Contract Document Conflicts 8. Delay in Resolving Disputes 9. Ambiguous Contract Terms 10. Extremely Competitive Tender
RG2—Client-Related Risks	11. Variations by Client 12. Problems Arising due to Lack of Experience by Client 13. Project Funding Problems 14. Change in Design by Client
RG3—Physical Risks	15. Unexpected Site Conditions 16. Loss or Damage by Fire or Flood 17. Local Concerns and Requirements 18. Fluctuation in Material Price/Material Shortage

R.Q #1: What are the main critical success factors of a successful project?

This comparison between SIDS and other developing economies will assist in the understanding of any variability in risk based on varying geographies and economies. To address the second objective, i.e., the acquisition of relevant perception data from various construction professionals in Trinidad and Tobago, and to defuzzify these perceptions into clear quantitative measures, the second research question is as follows:

R.Q #2: Which risk factor has the highest overall risk impact by means of fuzzy synthetic evaluation?

This question allows for contemporary field data to be gathered through a closed-ended questionnaire tool. The participants' perceptions are then validated and processed using soft computing modeling known as fuzzy synthetic evaluation (FSE). The FSE model will provide an empirical multicriteria risk-ranking assessment of various critical risk groupings and associated risk factors. Finally, the third objective is to provide effective recommendations to mitigate these critical factors using critical success factors derived from the literature. Consequently, the final research question is as follows:

R.Q #3: What are the mitigation measures for the CRFs leading to cost overrun?

3. Research Methodology

Based on the current ideological distancing in cost overrun studies [34], this study adopted a post-positivist philosophical paradigm, aligning with the critical realism framework, to understand the causal relationships among mechanisms, events and observations. Therefore, a three-step mixed-method approach was adopted, namely a sequential exploratory design, to achieve the objectives of this study. The first step entailed a qualitative phase of data gathering and collection. Qualitative research involves the collection and interpretation of non-numerical data in order to understand how different individuals perceive different ideologies. The qualitative approach involved the identification of the risk factors and their associated risk groups through a review of the prior literature, especially that obtained in developing economies, which are the most relevant to the economy of Trinidad and Tobago. A comparative study was undertaken based on 18 CRFs and 3 CRGs as presented by Ameyaw et al. [6], who in turn adapted these factors from Odeyinka et al. [35]. The use of these factors is justified as Trinidad and Tobago's developing economy has faced similar challenges to the developing economies of Ghana, and its laws, contracts and construction practices are modeled against, and are derivatives of, the UK's regulatory system. The adoption of these factors can allow for theoretical comparisons and generalizations across varying geographic and social contexts. To validate the applicability of these factors within the SIDS context, a three-round Delphi survey was undertaken by a panel of three experts, two industry experts and one construction academic. The first round was to obtain a consensus on the applicability and validity of the CRFs and CRGs. The general responses obtained were addressed and then tailored into a questionnaire for the second-round Delphi consensus. Other CRFs recommended were included into the questionnaire. The final round solicited expert opinions on whether the new factors can be included into the original 18 CRFs or be a subset of such factors (for example, financing issues and client-related funding were included under CRF 13—project funding problems). The 18 critical risk factors and 3 CRGs are presented in Table 1.

The second step was quantitative in nature and entailed the implementation of the questionnaire survey method. This quantitative research instrument involved the collection and analysis of numerical data to test relationships between variables or make predictions. The closed-ended questionnaire was distributed to professionals in the public construction sector of Trinidad and Tobago. The questionnaire comprised three sections. Section 1 was the demographic section and collected basic non-personal background information about the professional, such as gender, years of experience, public or private employment and number of projects administered/involved. Section 2 lists the CRFs using ordinal scaling. Participants were asked to rate the probability and severity of each CRF based on a 7-point Likert system, to allow participants to express themselves regarding their level of agreement. For the probability scaling, point 1 was "extremely low" and point 7 was "extremely high". For the severity scaling, point 1 was "not significant" and point 7 was "extremely significant". Section 3 solicited tacit information by requesting participants to further elaborate on cost overrun issues. This was undertaken to derive richer and deeper insights that can inform theory within context-dependent events. All participants were informed of the ethical process involved in conducting this research. Participants were informed that the survey process was entirely voluntary and they could stop participating in the survey at any point in time, without any reason or justification. They were also assured that no personal data would be gathered, and all responses were anonymized to protect their identities and prevent any breach of confidentiality.

The third step of the mixed-method research design was to process the data through a fuzzy modeling technique called FSE. FSE was selected since the cost overrun phenomenon consists of multi-tiered and multicriteria CRFs and CRGs, and these risk mechanisms and structures possess a veil of transparency, where the perceptions of participants vastly vary. This then adds to the increased complexity and uncontrollability in risk management, leading to imprecision in measurement and ineffective controls. FSE is adopted to remove such imprecisions in the rating criteria and determine clear empirical values for risk quantification and decision making. FSE is a method based on fuzzy subsets that replaces the logical deductions of traditional two-valued classical sets [6], and it is applied in the following steps:

1. Create an evaluation index system where the CRF of each CRG, F, is assigned a basic criterion, that is, f1, f2, f3 . . . . fn.
2. Establish the set of alternatives, E = {e1, e2, en . . . }, where e is the perception scoring of survey respondents, using rating scales such as the Likert scale.
3. Determine weightings of the CRFs and CRGs for mean probability and severity, W = {w1, w2, . . . , wn}, where w is the set of weightings. The weightings of the CRFs and CRGs for probability and severity were obtained using the following formulas:

Weighting of CRF = [mean probability or severity of CRF]/[total mean probability or severity for the associated CRG] (1)

Weighting of CRG = [mean probability or severity of CRG]/[total mean probability of all CRGs] (2)

4. The membership functions of the CRFs and CRGs are determined for both probability and severity. The membership function is a matrix displaying the percentage of respondents selecting a particular value on the Likert scale for a particular CRF. For a 7-point Likert scale, the membership function (MF) can be represented as

$$\mathrm{MF} = \frac{\mathrm{N_{1j}}}{\mathrm{X}} \times 100, \frac{\mathrm{N_{2j}}}{\mathrm{X}} \times 100, \frac{\mathrm{N_{3j}}}{\mathrm{X}} \times 100, \ldots, \frac{\mathrm{N_{ij}}}{\mathrm{X}} \times 100 \quad (3)$$

where R_{ij} = the number for respondents, N, who selected a score, i, for probability or severity (i = {1,2 . . . ..7} in the case of the 7-point scale) for a critical risk factor, j.

5. The fuzzy evaluation matrix is then set up given that the alternative, ei, satisfies the basic criterion, fj, following Equation (4):

$$\mathrm{R} = (r_{ij})_{m\times n} \cdot r_{ij} \quad (4)$$

6. The final fuzzy evaluation is done using the weightings, W, and the fuzzy evaluation matrix, R, as shown in Equation (5). This was repeated for all three levels of the membership function.

$$\mathrm{D} = \mathrm{W} \circ \mathrm{R} \quad (5)$$

where D = the final fuzzy evaluation, W = the vector of weighting, R = the matrix of evaluation from Equation (4) and ∘ = operator for fuzzy composition.

7. This derived Equation (5) is the FSEM that will be applied for calculations of both the probability and severity levels and can be quantified for a given risk level $\mathrm{RL_i}$ as shown.

$$RL_i = \sum_{i=1}^{7} \bar{D}_i \times V^t = \left(D'_1, D'_2, D'_3, D'_4, D'_5, D'_6, D'_7\right) \times (1,2,3,4,5,6,7) \text{ for } 1 \le RL_i \le 7 \quad (6)$$

where V^t is the specific linguistic scaling for both probability and severity.

8. The risk impact of each risk factor was determined by Equation (7).

$$Risk\ Impact = \sqrt{mean\ probabiliy \times mean\ severity} \quad (7)$$

9. Finally, the overall risk level (ORL) can be obtained by combining the risk levels of probability and severity,

$$ORL = \sqrt{\left(\sum_{p=1}^{7} \bar{D}_p \times V^t\right) \times \left(\sum_{s=1}^{7} \bar{D}_s \times V^t\right)},\ 1 \leq ORL \leq 7 \quad (8)$$

The workflow of the overall study's methodology is summarized in Figure 1.

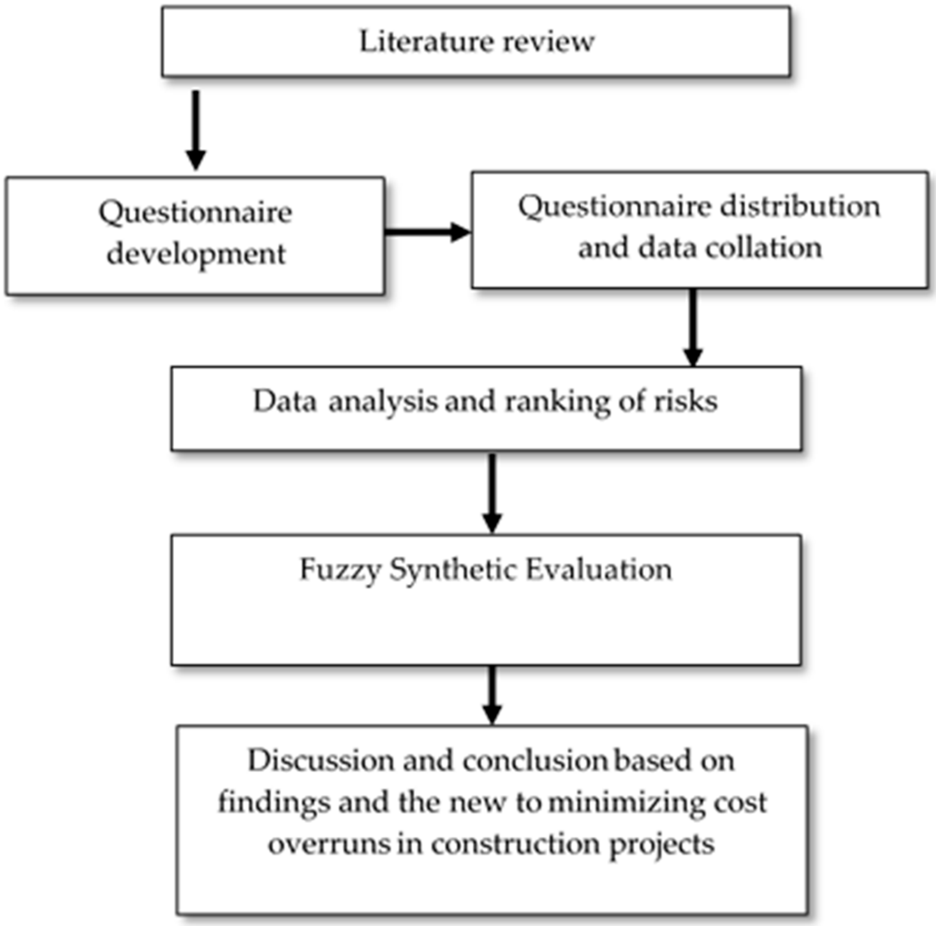

Figure 1. Workflow of the study.

4. Results and Discussion

A total of 52 responses from various professionals in the construction industry of Trinidad and Tobago were collected for analysis. The data were verified for completeness prior to data processing. The data gathered from this section were based on categories such as the sector of employment—that is, public or private—profession, experience level and types of construction projects involved. The demographics of the respondents based on Section 1 of the questionnaire and the frequency for each category were calculated and are presented in Table 2.

In terms of the sector of employment, 61.5% of the respondents were from the public sector and 38.5% were from the private sector. The majority of the respondents being from the public sector was favorable for the research as variations in the contract sums of public sector projects pose several constraints that require uncovering and unpacking. Moreover, respondents' involvement in public sector projects meant that they could provide more reliable data. From a profession standpoint, 67.3% of respondents were in the engineering profession, 17.3% in contracting, 9.6% in project management and 5.8% in consulting. Of these various professionals, the majority had experience on the lower end of 0–5 years with a frequency of 48.1%, while those with more than 20 years' experience only represented 9.6% of the sample size. This skewness towards 0 to 5 years' experience does not reduce the validity of the results as they express the views of a modern generation of construction professionals. Additionally, the remaining respondents who would fall within the category of experienced professionals had 6 to more than 20 years of experience, which accounted for the remaining 51.9% of the experience levels of the respondents. Cumulatively, the majority of the respondents were experienced professionals in the construction sector.

Table 2. Demographics of respondents.

Category	Respondents	
	Frequency	Percentage
Sector		
Public	32	61.5
Private	20	38.5
Profession		
Engineering	35	67.3
Contracting	9	17.3
Project Management	5	9.6
Architecture	0	0.0
Consulting	3	5.8
Experience Level		
0–5 years	25	48.1
6–10 years	14	26.9
11–15 years	6	11.5
16–20 years	2	3.80
>20 years	5	9.60
Type of Construction Project		
Transportation Projects	8	15.4
Commercial Projects	5	9.60
Water/Wastewater Treatment Projects	9	17.3
Housing Projects	17	32.7
Civil Engineering Projects	13	25.0

Furthermore, there was a range of respondents who participated in different construction projects, such as transportation, commercial, water/wastewater treatment, housing and civil engineering, which had frequencies of 15.4%, 9.6%, 17.3%, 32.7% and 25%, respectively. This distribution of the types of projects undertaken by respondents allowed for different perspectives from various types of projects governed by their own unique design approaches, contractual arrangements and physical conditions, among others. Thus, the respondents could provide unique views on each project type regarding the risk factors leading to variations in contract sums. The risk impact was assessed as a combination of the probability of occurrence and the severity of the event, and the average risk estimation was computed using this well-established framework for risk quantification [5,18]. The mean risk probability and severity for each of the 18 risk factors were calculated from the raw data obtained and were subsequently ranked to provide a clear indication of the most probable and highest-severity CRFs based on the professional responses. The multiple of the risk probability and severity for each risk factor produced the risk significance index (RSI), which showed the overall ranking of the risk factors (Table 3). This overall rank indicated the CRFs most significantly contributing to COs.

Table 3. Ranking of risk probability and severity and risk significance index.

Risk Factor	Risk Probability Mean	Risk Probability Rank	Risk Severity Mean	Risk Severity Rank	RSI	Risk Impact	Overall Rank	Normalized Value
Project Funding Problems	5.83	2	6.50	1	37.88	6.15	1	1.0
Variations by Client	5.60	3	5.98	3	33.47	5.79	2	0.9
Change in Design by Client	5.87	1	5.50	6	32.26	5.68	3	0.9
Underestimation of Quantities	4.73	5	6.04	2	28.57	5.34	4	0.8
Inadequate Specification	4.62	6	5.65	5	26.09	5.11	5	0.8
Unexpected Site Conditions	4.96	4	5.17	7	25.67	5.07	6	0.7
Fluctuation in Material Price/Material Shortage	4.15	7	5.15	8	21.41	4.63	7	0.6
Change in Scope of Works	3.44	12	5.69	4	19.59	4.43	8	0.6
Defects in Design	3.63	9	4.63	10	16.85	4.10	9	0.5
Ambiguous Contract Terms	3.60	10	4.31	12	15.49	3.94	10	0.5
Problems Arising due to Lack of Experience by Client	3.56	11	4.25	13	15.12	3.89	11	0.5
Change in Design by Architect	3.08	14	4.52	11	13.91	3.73	12	0.4
Loss or Damage by Fire or Flood	2.25	16	4.94	9	11.12	3.33	13	0.3
Delay in Resolving Disputes	3.79	8	2.75	14	10.42	3.23	14	0.3
Extremely Competitive Tender	3.27	13	1.69	18	5.53	2.35	15	0.1
Third-Party Delays	2.35	15	2.04	17	4.78	2.19	16	0.1
Contract Document Conflicts	1.75	17	2.29	15	4.00	2.00	17	0.0
Local Concerns and Requirements	1.71	18	2.17	16	3.72	1.93	18	0.0

Table 4 below provides a comparison of the CRF rankings and their corresponding RSIs generated in this study to the results found in the Ghanian context [6]. It is observed that although both research works draw data from a different geographic (Caribbean vs. Africa) and population (1.5 million vs. 33 million) context, the risk rankings bear similarities and are comparable. CRFs such as project funding problems, underestimation of quantities, variations by client and inadequate specifications are four of the top five CRFs leading to CO challenges in both Trinidad and Ghana. A causal inference can be built with these factors: project funding problems are created due to variations by the client. Variations can be derived from altering the designs based on inadequate specifications or the underestimation of quantities in the tender documents. However, it is also noted that the comparable RSI in the Trinidadian context is higher than in the Ghanian context, indicating that professionals in the SIDS construction industry weight these CRFs with a higher risk impact than the African/Ghanian practitioners. This may be due to the smaller, more volatile economic conditions in SIDS, being dependent on larger western economies, and constraints to the economies of scale in resource allocation and construction material production [3].

In applying the FSE modeling, the criticality of the risk factors selected to undergo defuzzification was determined by normalizing the risk impact values. Risk ≥ 0.5 was deemed critical, and 11 of the 18 risks were selected for modeling. To perform the FSE, the first step is the determination of the weightings of the CRFs and CRGs. These weightings are calculated by normalizing the average values of each critical risk factor, which were acquired from the 52 responses received. Subsequently, the membership functions were then calculated in three tiers: tier 3 and tier 2 are the membership functions of the CRFs and CRGs, and tier/level 1 is the membership function of the overall risk (refer to Tables 5–7).

Table 4. Comparative analysis with Ameyaw et al. [6].

ID	Risk Factor	This Study RSI	This Study Rank	Ameyaw et al. [6] RSI	Ameyaw et al. [6] Rank
13	Project Funding Problems	37.88	1	34.99	1
11	Variations by Client	33.47	2	30.14	3
14	Change in Design by Client	32.26	3	28.35	6
1	Underestimation of Quantities	28.57	4	33.15	2
5	Inadequate Specification	26.09	5	28.84	5
15	Unexpected Site Conditions	25.67	6	27.18	8
18	Fluctuation in Material Price/Material Shortage	21.41	7	21.38	12
2	Change in Scope of Works	19.59	8	30.06	4
4	Defects in Design	16.85	9	27.20	7
9	Ambiguous Contract Terms	15.49	10	22.86	11
12	Problems Arising due to Lack of Experience by Client	15.12	11	20.37	13
3	Change in Design by Architect	13.91	12	23.90	10
16	Loss or Damage by Fire or Flood	11.12	13	18.69	16
8	Delay in Resolving Disputes	10.42	14	24.30	9
10	Extremely Competitive Tender	5.53	15	17.55	18
6	Third-Party Delays	4.78	16	20.26	14
7	Contract Document Conflicts	4.00	17	19.63	15
17	Local Concerns and Requirements	3.72	18	18.49	17
	Sample (n)	52		42	
	Measurement (Likert) scale	7-pt.		7-pt.	

Table 5. Membership functions for all CRFs and CRG: probability.

CRFs and CRGs	Weighting for CRFs	Membership Function for Tier 3 (CRFs)	Membership Function for Tier 2 (CRGs)
Client-Related Risks (CRG 1):			(0.000, 0.013, 0.069, 0.100, 0.286, 0.399, 0.133)
Project Funding Problems	0.280	(0.00, 0.00, 0.00, 0.00, 0.33, 0.52, 0.15)	
Variations by Client	0.268	(0.00, 0.00, 0.00, 0.12, 0.31, 0.44, 0.13)	
Change in Design by Client	0.281	(0.00, 0.00, 0.00, 0.00, 0.33, 0.48, 0.19)	
Problems Arising due to Lack of Experience by Client	0.171	(0.00, 0.08, 0.40, 0.40, 0.12, 0.00, 0.00)	
Professional-Related Risks (CRG 2):			(0.000, 0.037, 0.219, 0.412, 0.291, 0.041, 0.000)
Underestimation of Quantities	0.236	(0.00, 0.00, 0.02, 0.37, 0.48, 0.13, 0.00)	
Inadequate Specification	0.231	(0.00, 0.00, 0.04, 0.35, 0.58, 0.04, 0.00)	
Change in Scope of Works	0.172	(0.00, 0.13, 0.35, 0.46, 0.06, 0.00, 0.00)	
Defects in Design	0.182	(0.00, 0.00, 0.46, 0.44, 0.10, 0.00, 0.00)	
Ambiguous Contract Terms	0.180	(0.00, 0.08, 0.35, 0.48, 0.10, 0.00, 0.00)	
Physical Risks (CRG 3):			(0.000, 0.000, 0.044, 0.434, 0.428, 0.073, 0.021)
Unexpected Site Conditions	0.544	(0.00, 0.00, 0.00, 0.25, 0.58, 0.13, 0.04)	
Fluctuation in Material Price/Material Shortage	0.456	(0.00, 0.00, 0.10, 0.65, 0.25, 0.00, 0.00)	

The following calculations provide guidance in undertaking FSE modeling using the CRF u_{11} (*project funding problems*) as an example.

The weighting functions of the CRFs (tier 3) and CRGs (tier 2) were calculated from the mean values. From Table 8, CRG 1, client-related risks (u_1), consists of four (4) CRFs with a mean total probability value of 25.63.

Table 6. Membership functions for all CRFs and CRG: severity.

CRFs and CRGs	Weighting for CRFs	Membership Function for Tier 3 (CRFs)	Membership Function for Tier 2 (CRGs)
Client-Related Risks (CRG 1):			
Project Funding Problems	0.292	(0.00, 0.00, 0.00, 0.00, 0.04, 0.42, 0.54)	(0.000, 0.000, 0.033, 0.085, 0.293, 0.346, 0.244)
Variations by Client	0.269	(0.00, 0.00, 0.00, 0.00, 0.27, 0.48, 0.25)	
Change in Design by Client	0.247	(0.00, 0.00, 0.00, 0.00, 0.58, 0.35, 0.08)	
Problems Arising due to Lack of Experience by Client	0.191	(0.00, 0.00, 0.17, 0.44, 0.35, 0.04, 0.00)	
Professional-Related Risks (CRG 2):			
Underestimation of Quantities	0.229	(0.00, 0.00, 0.00, 0.00, 0.17, 0.62, 0.21)	(0.000, 0.000, 0.042, 0.145, 0.353, 0.341, 0.119)
Inadequate Specification	0.215	(0.00, 0.00, 0.00, 0.04, 0.44, 0.35, 0.17)	
Change in Scope of Works	0.216	(0.00, 0.00, 0.00, 0.00, 0.46, 0.38, 0.15)	
Defects in Design	0.176	(0.00, 0.00, 0.08, 0.37, 0.40, 0.15, 0.00)	
Ambiguous Contract Terms	0.164	(0.00, 0.00, 0.17, 0.44, 0.29, 0.10, 0.00)	
Physical Risks (CRG 3):			
Unexpected Site Conditions	0.501	(0.00, 0.00, 0.00, 0.17, 0.50 0.31, 0.02)	(0.000, 0.000, 0.000, 0.115, 0.615, 0.260, 0.010)
Fluctuation in Material Price/Material Shortage	0.499	(0.00, 0.00, 0.00, 0.06, 0.73 0.21, 0.00)	

Table 7. Determination of membership functions of overall risk index (Level 1).

Critical Risk Groups (PRGs)	Weighting for CRGs	Membership Functions of Tier 2 (CRGs)	Membership Functions of Tier 1 (ORL)
Risk Probability:			
Client-Related Risks (PRF 1):	0.417	(0.000, 0.013, 0.069, 0.100, 0.286, 0.399, 0.133)	(0.000, 0.020, 0.124, 0.286, 0.314, 0.196, 0.059)
Professional-Related Risks (PRF 2):	0.401	(0.000, 0.037, 0.219, 0.412, 0.291, 0.041, 0.000)	
Physical Risks (PRF 3):	0.182	(0.000, 0.000, 0.044, 0.434, 0.428, 0.073, 0.021)	
Risk Severity:			
Professional-Related Risks (PRF 2):	0.447	(0.000, 0.000, 0.042, 0.145, 0.353, 0.341, 0.119)	(0.000, 0.000, 0.031, 0.117, 0.376, 0.329, 0.147)
Client-Related Risks (PRF 1):	0.378	(0.000, 0.000, 0.033, 0.085, 0.293, 0.346, 0.244)	
Physical Risks (PRF 3):	0.175	(0.000, 0.000, 0.000, 0.115, 0.615, 0.260, 0.010)	

The weighting function of u_{11} (*project funding problems*) can be quantified as follows:

$$w_{u_{11}} = \frac{5.83}{5.83 + 5.60 + 5.87 + 3.56} = \frac{5.83}{20.86} = 0.279 \tag{9}$$

The normalized weighting set of CRG1 is satisfied by (10)

$$\sum_{i=1}^{7} 0.279 + 0.268 + 0.281 + 0.171 = 1.00 \tag{10}$$

The weighing of each CRF, within CRG1, CRG2 and CRG3, was computed using the same procedure.

The weighting of each CRG for both probability and severity was derived in the same manner using Equation (4). Thus, the total probability mean values of the CRG categories are u_1 = 20.86 (client-related), u_2 = 20.02 (professional-related) and u_3 = 9.11 (physical-related).

$$w_{u_1} = \frac{20.86}{20.86 + 20.02 + 9.11} = 0.417$$

Similarly, $w_{u_2} = 0.4$, $w_{u_3} = 0.182$.

In addition, the weights of the CRGs as they relate to risk severity were obtained.

Table 8. Table showing weightings for 11 CRFs and 3 CRGs for cost impacts in public sector projects.

Critical Risk Factors (CRFs)	**Risk probability (*p*)**				**Risk severity (*s*)**			
	Mean Probability	**CRF Weighting**	**Total Mean of CRG**	**CRG Weighting**	**Mean Severity**	**CRF Weighting**	**Total Mean of CRG**	**CRG Weighting**
Project Funding Problems	5.83	0.280			6.50	0.292		
Variations by Client	5.60	0.265			5.98	0.269		
Change in Design by Client	5.87	0.281			5.50	0.247		
Problems arising due to lack of experience by client	3.56	0.171			4.25	0.191		
Client Related Risks (CRG 1) : u_1			20.85	0.417			22.23	0.378
Underestimation of Quantities	4.73	0.236			6.04	0.229		
Inadequate Specification	4.62	0.231			5.65	0.215		
Change in Scope of Works	3.44	0.172			5.69	0.216		
Defects in Design	3.63	0.182			4.63	0.176		
Ambiguous Contract Terms	3.60	0.180			4.31	0.164		
Professional Related Risks (CRG 2) : u_2			20.02	0.401			26.33	0.447
Unexpected Site Conditions	4.96	0.544			5.17	0.501		
Fluctuation in Material Price/Material Shortage	4.15	0.456			5.15	0.499		
Physical Risks (CRG 3) : u_3			9.12	0.182			10.33	0.17
Total of mean values of PRFs			49.98				58.88	

4.1. Determination of the Membership Functions

Continuing the example of the CRF "project funding problems, (u_{11})", the survey data showed that the 52 respondents rated the probability of occurrence as follows: 0% as "extremely low", 0% as "very low", 0%, as "low", 0% as "moderate", 33% as "high", 52% as "very high" and 15% as "extremely high". Therefore, the MF (risk probability) of u_{11} was obtained using Equation (1) as

$$MF_{u_{11_{probability}}} = \frac{0.00}{Extremely\ low} + \frac{0.00}{Very\ low} + \frac{0.00}{Low} + \frac{0.00}{Moderate} + \frac{0.33}{High} + \frac{0.52}{Very\ High} + \frac{0.15}{Extrememly\ High}$$

The membership functions of all 11 CRFs, based on how respondents perceived the probability of the risk occurring, are shown in Table 6. Similarly, for severity, of the 52 respondents, the percentage responses rating the severity of the CRF "project funding problems" were 0% as "extremely low", 0% as "very low", 0% as "low", 0% as "moderate", 4% as "high", 42% as "very high" and 54% as "extremely high". The risk severity MF of u_{11} is represented as

$$MF_{u_{11_{severity}}} = \frac{0.00}{Extremely\ low} + \frac{0.00}{Very\ low} + \frac{0.00}{Low} + \frac{0.00}{Moderate} + \frac{0.04}{High} + \frac{0.42}{Very\ High} + \frac{0.54}{Extrememly\ High}$$

Hence, the MFs of "project funding problems, (u_{11})" for both probability and severity can be obtained through Equation (2) as (0.00, 0.00, 0.00, 0.00, 0.33, 0.52, 0.15) and (0.00, 0.00, 0.00, 0.00, 0.04, 0.42, 0.54), respectively. This approach is repeated for the MFs for each specific CRF. Table 6 summarizes probability MFs, while Table 7 summarizes severity MFs for both CRFs and CRGs.

After computing the MFs of the CRFs, weighting function sets were required to compute the MFs of the CRGs (Tables 6 and 7). To demonstrate the computation of the MFs for CRG 1 (client-related risks (u_1)), the MFs for the probability of all four CRFs within the CRG 1 category were stated in a fuzzy matrix as

$$R_{u1_{(p)}} = \begin{vmatrix} MF_{u_{11}} \\ MF_{u_{12}} \\ MF_{u_{13}} \\ MF_{u_{14}} \end{vmatrix} = \begin{vmatrix} 0.00 & 0.00 & 0.00 & 0.00 & 0.33 & 0.52 & 0.15 \\ 0.00 & 0.00 & 0.00 & 0.12 & 0.31 & 0.44 & 0.13 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.33 & 0.48 & 0.19 \\ 0.00 & 0.08 & 0.40 & 0.40 & 0.12 & 0.00 & 0.00 \end{vmatrix}$$

The fuzzy evaluation matrix considers the weighting functions of the CRFs within u_1 (CRG1) such that

$$D_{u1(p)} = W_{u1(probability)} \times R_{u1(probability)} = (w_{11}, w_{12}, w_{13}, w_{14}) \times \begin{vmatrix} MF_{u_{11}} \\ MF_{u_{12}} \\ MF_{u_{13}} \\ MF_{u_{14}} \end{vmatrix}$$

$$D_{u1(p)} = (0.28, 0.268, 0.0.281, 0.211, 0.171) \times \begin{vmatrix} 0.00 & 0.00 & 0.00 & 0.00 & 0.33 & 0.52 & 0.15 \\ 0.00 & 0.00 & 0.00 & 0.12 & 0.31 & 0.44 & 0.13 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.33 & 0.48 & 0.19 \\ 0.00 & 0.08 & 0.40 & 0.40 & 0.12 & 0.00 & 0.00 \end{vmatrix}$$

$$D_{u1(p)} = (0.000, 0.013, 0.069, 0.100, 0.286, 0.399, 0.133)$$

Similarly, the fuzzy evaluation matrix of the severity of u_1 (CRG1) is obtained using the weight function for severity as follows:

$$D_{u2(s)} = (0.292, 0.269, 0.247, 0.191) \times \begin{vmatrix} 0.00 & 0.00 & 0.00 & 0.00 & 0.04 & 0.42 & 0.54 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.27 & 0.48 & 0.25 \\ 0.00 & 0.00 & 0.00 & 0.00 & 0.58 & 0.35 & 0.08 \\ 0.00 & 0.00 & 0.17 & 0.44 & 0.35 & 0.04 & 0.00 \end{vmatrix}$$

$$D_{u2(s)} = (0.000, 0.000, 0.033, 0.085, 0.293, 0.346, 0.244)$$

4.2. Determination of Overall Risk Level (ORL)

The final step of the FSE requires normalizing the obtained fuzzy evaluation matrices $D_i(i = u_1, u_2, u_3)$ for the CRGs (level 2) by considering their weight functions to generate the final fuzzy evaluation matrix of ORL (i.e., tier or level 1). From Tables 6 and 7, the MFs of the tier 2 CRGs for both the probability and severity matrices are represented as

$$\overline{R}_{(p)} = \begin{vmatrix} D_{u_1} \\ D_{u_2} \\ D_{u_3} \end{vmatrix} = \begin{vmatrix} 0.000 & 0.013 & 0.069 & 0.100 & 0.286 & 0.399 & 0.133 \\ 0.000 & 0.037 & 0.219 & 0.412 & 0.291 & 0.041 & 0.000 \\ 0.000 & 0.000 & 0.044 & 0.434 & 0.428 & 0.073 & 0.021 \end{vmatrix}$$

$$\overline{R}_{(s)} = \begin{vmatrix} D_{u_1} \\ D_{u_2} \\ D_{u_3} \end{vmatrix} = \begin{vmatrix} 0.000 & 0.000 & 0.042 & 0.145 & 0.353 & 0.341 & 0.119 \\ 0.000 & 0.000 & 0.033 & 0.085 & 0.293 & 0.346 & 0.244 \\ 0.000 & 0.000 & 0.000 & 0.115 & 0.615 & 0.260 & 0.010 \end{vmatrix}$$

Given the probability weighting function set as $\overline{W} = \{0.417, 0.401, 0.182\}$, the final fuzzy evaluation matrix of the overall risk probability level of CO is calculated as follows:

$$\overline{D}_{(p)} = \begin{vmatrix} 0.417 \\ 0.401 \\ 0.182 \end{vmatrix} \times \begin{vmatrix} 0.000 & 0.013 & 0.069 & 0.100 & 0.286 & 0.399 & 0.133 \\ 0.000 & 0.037 & 0.219 & 0.412 & 0.291 & 0.041 & 0.000 \\ 0.000 & 0.000 & 0.044 & 0.434 & 0.428 & 0.073 & 0.021 \end{vmatrix}$$

$$\overline{D}_{(p)} = (0.000, 0.020, 0.124, 0.268, 0.314, 0.196, 0.059)$$

Similarly, the final fuzzy evaluation matrix of the overall risk severity level is quantified as

$$\overline{D}_{(s)} = \begin{vmatrix} 0.447 \\ 0.378 \\ 0.175 \end{vmatrix} \times \begin{vmatrix} 0.000 & 0.000 & 0.042 & 0.145 & 0.353 & 0.341 & 0.119 \\ 0.000 & 0.000 & 0.033 & 0.085 & 0.293 & 0.346 & 0.244 \\ 0.000 & 0.000 & 0.000 & 0.115 & 0.615 & 0.260 & 0.010 \end{vmatrix}$$

$$\overline{D}_{(s)} = (0.000, 0.000, 0.031, 0.117, 0.376, 0.329, 0.147)$$

The results for the ORL are shown in Table 8.

Using the fuzzy matrix of each CRG, the tier 2 risk levels can be quantified by adopting the basic formula in which the risk is the square root of the product of probability and severity. Thus, for a 7-point membership function, the risk level of each CRG 1 is

$$\begin{aligned} RL_1 &= \sqrt{(0.000 \times 1 + 0.013 \times 2 + 0.069 \times 3 + 0.100 \times 4 + 0.286 \times 5 + 0.399 \times 6 + 0.133 \times 7)} \\ &\times \sqrt{(0.000 \times 1 + 0.000 \times 2 + 0.042 \times 3 + 0.145 \times 4 + 0.353 \times 5 + 0.341 \times 6 + 0.119 \times 7)} \\ &= \sqrt{5.389 \times 5.351} = 5.370 \end{aligned}$$

Finally, the tier 1 overall risk level (ORL) of CO for public projects in Caribbean SIDS (Table 9) was quantified as follows:

$$ORL_{CO} = \sqrt{\begin{matrix} (0.000 \times 1 + 0.002 \times 2 + 0.124 \times 3 + 0.286 \times 4 + 0.314 \times 5 + 0.196 \times 6 + 0.059 \times 7) \times \\ (0.000 \times 1 + 0.000 \times 2 + 0.031 \times 3 + 0.117 \times 4 + 0.376 \times 5 + 0.329 \times 6 + 0.147 \times 7) \end{matrix}}$$

$$ORL_{CO} = \sqrt{4.719 \times 5.443} = 5.068$$

Table 9. Overall risk levels of the critical risk groups.

Critical Risk Group (CRG)	Probability of Occurrence Index	Linguistic	Severity Index	Risk Level Index	Linguistic	Ranking
Client-Related Risks (CRG 1):	5.389	High	5.351	5.370	High	1
Professional-Related Risks (CRG 2):	4.080	Moderate	5.683	4.815	High	3
Physical Risks (CRG 3):	4.593	High	5.163	4.870	High	2
Overall Risk Level (ORL):	4.719	High	5.443	5.068	High	-

A comparison can be made with the results found in research done by Ameyaw et al. [6], which, through the fuzzy synthetic evaluation method, determined professional-related factors to have the highest risk impact, followed by client-related factors. This shows that these two risk groups share a common ground in terms of impact in the developing economy of Ghana as well as in Trinidad and Tobago. In terms of the client-related factors, as seen in Table 4, variations by clients are among the top risk factors (RI = 5.79), followed by changes in design by clients (RI = 5.68), implying that clients in developing countries more often request the original design to be redone in order to fulfil the requirements set out by the new and emerging economic conditions, as well as laws passed by the governing bodies. Contrastingly, in the developed economy of Australia, a fuzzy risk assessment model for guaranteed maximum price and target cost contracts concluded that physical risks were the major challenge in achieving budgetary control [5]. An assumption can be proposed that developed economies have a more advanced and modern approach to public sector construction management, and proper mitigation methods and strategies are better implemented for client-related risk factors and professional-related risk factors. However, physical risks present problems in SIDS; the physical factors critical risk group ranked highly in terms of risk level (risk index = 4.870). Unforeseeable ground conditions were among the critical risk factors in developed nations such as the United Kingdom, as well as Hong Kong [5]. From the results obtained, unexpected site conditions have a risk impact of 5.07 and are ranked sixth among the principal risk factors. Therefore, it can be inferred that physical risks are a common problem in terms of risk level in both developed and emerging economies of SIDS.

The three critical risk groups that classified the 11 critical risk factors—that is, client-related risks, professional-related risks and physical risks—were used as input variables and generated one output, the overall risk level (ORL). The overall risk level defines the degree to which the 11 critical risk factors affect the variability in contract sums. Table 9 shows the overall risk levels of the critical risk groups. The risk level index of the individual CRGs was calculated to be 5.370, 4.815 and 4.870 for client-related risks, professional-related risks and physical risks, respectively, with client-related factors being ranked as number 1. The overall risk level (ORL) of the three critical risk groups was calculated to be 4.719, which shows that these critical risk groups have a high degree of impact on public sector projects. These risk level values were all classified as high-risk on a linguistic scale based on their individual probability and severity risk indexes. These results are important for practice and demonstrate the need for detailed risk assessments based on holistic approaches to complement individual projects' qualitative risk assessment criteria. In public projects, the main focus for professionals is to detect and control risks from other main stakeholders, such as the contractor, and little regard is given to the causal implications of delays, extensions of time and disruption costs suffered by the contractors because of the state agency's inability to deliver much-needed cash flows in a timely manner [34]. These results inform the client's team that the greatest risk is the client, and more immediate controls are required to manage themselves while concurrently focusing on CRGs such as professional- and physical-related risks. Similar findings were noted in the comparative context of Ghana, where, of the two CRGs, "client factors" carry more risks than "professional-related factors". These results signal to state agencies to conduct an inward evaluation of their competencies, human resources, processes and governance structures to align project controls for improved due diligence and accountability in decision making. Consequentially, more informed and accountable decision making leads to sustainable choices and reduced overruns in costs on public-sector-led projects [36].

The CRF project funding problems had the highest risk impact (RI = 6.15) and ranked first in the list of 18 CRFs. This risk factor belongs to the CRG of client-related risks, which scored the highest risk level index of 5.370 among the three critical risk groups. This shows that project funding problems are the greatest risk, with the highest impact on public sector projects in the developing economies, which was also the case in the Ghanaian context. Conversely, this was not the case in the United Kingdom, where project funding problems are one of the least significant risks associated with COs [11]. This highlights the large gap in economic development, infrastructure, capacity and competence to acquire the needed funding for public sector projects in emerging economies.

With regard to professional-related risks, this critical risk group was ranked third in terms of risk level index, having a value of 4.815, for which the critical risk factors in terms of risk significance were identified, which included the underestimation of quantities (RI = 5.34, rank 4), followed by inadequate specification (RI = 5.11, rank 5), changes in the scope of works (RI = 4.43, rank 8), defects in design (RI = 4.10, rank 9) and ambiguous contract terms (RI = 3.94, rank 10). The underestimation of quantities usually stems from the tendering stage of any construction process and it can be linked to various reasons, such as a lack of experience by the project estimators or by a lack of complete drawings and material requirements at the time of the cost estimation [13]. Additionally, the underestimation of cost leads to an inaccurate tender sum being submitted, and if this inaccurate tender sum is the lowest, it is often awarded the contract in the case of developing economies. Clients then have the perception that this tender sum will not be exceeded; however, this is not the case as, at finalization, public infrastructure projects regularly surpass their tender cost budgets [12] and sometimes the underestimation of quantities is performed intentionally as a means of obtaining extra funding throughout the course of the project [6]. In research presented by [18], a fuzzy synthetic evaluation was conducted for risk assessment in Singapore's green projects, in which inaccurate cost estimation is the highest-ranking risk factor, implying that, even in a developed economy, inaccurate cost estimation is still a concerning risk factor that needs to be managed.

Inadequate specifications, as a critical risk factor under the professional critical risk group, is also a factor to consider as these types of specifications can cause changes in the original contract, which would in turn drastically increase the project cost. Furthermore, the provision of inadequate specifications in materials, for example, can cause the contracting agency to provide materials that serve basic purposes without satisfying the needs of the more important job objectives [37]. Deterioration processes, sustainability, maintainability and the service life of building materials are all essential aspects to be considered during the specification and selection of materials [30], especially in the case of emerging economies, since they have less substantial financial resources; the implication of inadequate specifications can be high cost overruns for public infrastructure projects, especially for the governing body who is the client.

Changes in the scope of works and defects in design, which are ranked as the critical risk factors under the professional critical risk group, can be linked together as deviating from the initial project scope that was agreed to in the contract (ambiguous contract terms, RI = 3.94) can ultimately lead to the design being defective [26], as the design would have been created for the initial conditions of the project. An example of a change in the scope of works is the changing of the specifications of the infrastructure being built, such as changing materials for a structure.

Based on the short-answer responses on COs obtained from the questionnaire, respondents were of the opinion that the construction phase of a project is most likely to give rise to COs. This is true in the sense that critical risk factors such as changes in the design by the client, underestimation of quantities and inadequate specifications are factors that are difficult to control during the construction phase but they can be managed before the start of the project to reduce the chances of COs. Additionally, 44.2% of respondents stated that client-related risks are the easiest risks to control in terms of preventing COs, as compared to professional-related factors and physical factors, which had frequencies of 30.8% and 25%, respectively. The most valid response for this was for the implication of set contract terms in order to prevent the client from requesting variations and design changes.

There are several implications that can be made with the results of the fuzzy synthetic evaluation as it can offer project managers a better understanding of the meaning behind the linguistic terms of risk categorization through the use of set values that define the linguistic meanings of high and low risk factors. The typical risk assessment method uses the most basic scoring system, which does not produce useful inferences that can be used by construction professionals as there are no reference data or means of analyzing the scores given; hence, they are referred to as fuzzy or shrouded data. Therefore, the fuzzy evaluation results provide a true insight into the impact of the risk factors affecting variations in COs.

5. Recommendations/Mitigation Methods to Minimize COs

The proposal for mitigative relief to minimize COs was derived from Section 3 of the questionnaire, which contained short-response questions for respondents to provide context-dependent mitigation strategies and techniques. The following points summarize suggestions that can be considered to minimize COs.

1. Mitigative relief for client-related CRGs: Complete and well-crafted contractual arrangements defining a set scope and criteria that must be fulfilled by both parties. The preference for this recommendation is based on the culture of procuring contractors with an incomplete tender package, with the explanation that other scope items will be completed in phases. A complete tender package and contractual documents allow the successful contractor to obtain a true funding arrangement and prevent the client from making unnecessary scope changes. On the other hand, the procurement of qualified contractors and sub-contractors who are prepared to undertake works based on accurate cost estimations is another mitigative strategy. Thus, contractors should account for any impacts caused by the critical risk factors in their cost estimation so

that the tender sum is not tightly predefined and there is a margin for error. This will mean that the existing procurement system is to be modified to move away from awarding the contracts simply to the lowest bidder, instead taking into consideration the capabilities, resources and experience of the contractor.

2. Mitigative relief for professional-related CRGs: The need for clear and effective communication among professionals is a reoccurring theme where state-led projects fall short in consistently implementing [2,3]. Hosting regular meetings with stakeholders at designated milestones during the project to ensure that the required work is being conducted and avoid any changes, which can minimize delays in decision making. This will allow for the use of effective project planning and scheduling.
3. Mitigation strategies were also recommended in the previous literature [4], which stated that a well-structured and simple payment process decreases resource requirements and enhances contractor relations, resulting in the increased operational efficiency of projects, project performance monitoring, acceptable user fee charges, open and constant communication and performance payment reductions. However, this is not as simple in SIDS. The main barriers to overcome are the governance and transparency issues, which unfortunately are beyond the control of the construction team and within the realm of political influence.

6. Conclusions

This study focused on controllable risk factors of COs in public sector projects, and utilized comparative scholarship to rank, assess and model critical risk factors. Root causes beyond the direct control of the primary stakeholders, such as political influences and force majeure events, were excluded from the scope of this study. Within the context of Trinidad and Tobago's construction industry, the collated data were processed and modeled using a fuzzy synthetic evaluation approach. The three critical risk groupings identified were client-related risks, professional-related risks and physical risks, each having an overall risk level index value of 5.370, 4.815 and 4.870, respectively. These risk index values show that client-related risk has the highest impact on the variability in the contract sums of public sector projects, while professional-related risk has the least impact of the three risk groups. The overall risk impact of these critical risk groups was determined to be 5.068, indicating that these critical risk groups have a high-risk impact in the economy of Trinidad and Tobago. Furthermore, these critical risk groups can be further broken down into 11 critical risk factors affecting variability in contract sums—that is, project funding problems, variations by client, changes in design by client, problems arising due to a lack of experience by the client, underestimation of quantities, inadequate specifications, changes in the scope of works, defects in design, ambiguous contract terms, unexpected site conditions and fluctuations in material prices. These critical risk factors were selected due to them having a normalization value of greater than or equal to 5, meaning that they are the most significant factors to consider in the Trinidad and Tobago economy. Consequently, recommendations for minimizing these COs were developed and are summarized in Section 5 under point 3. However, without appropriate governance structures and transparent processes, these critical risk factors will continue unabated. This study thus informs academic and construction practitioners of the salient risks to prioritize in public sector projects and potential mitigative strategies to steer projects within awarded contract sums.

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