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Feasibility Study for Construction Projects in Uncertainty Environment with Optimization Approach

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ABSTRACT

Construction projects are inherently complex and susceptible to various uncertainties throughout their lifecycle. These uncertainties can significantly impact project feasibility, leading to cost overruns, schedule delays, and reduced profitability. This paper explores the application of optimization approaches to enhance feasibility studies for construction projects in an uncertainty environment. We review existing literature on feasibility studies, uncertainty management, and optimization techniques in construction. The methodology proposes a framework for integrating uncertainty analysis and optimization into feasibility studies. A numerical example demonstrates the efficacy of the proposed framework by optimizing project schedules and resource allocation under different uncertainty scenarios. The results highlight the potential of optimization approaches to improve decision-making in feasibility studies, leading to more robust and reliable project assessments.

1. Introduction

The construction industry faces a constant challenge in ensuring the feasibility of projects during the initial planning stages. Feasibility studies play a critical role in determining a project's viability by evaluating its economic, technical, and operational aspects [1-3]. However, traditional feasibility studies often rely on deterministic approaches, assuming perfect information about project parameters. In reality, construction projects are subject to various uncertainties that can

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significantly impact their feasibility [5-7]. These uncertainties stem from diverse sources, including:

- **Material cost fluctuations:** material prices can fluctuate due to market forces, supply chain disruptions, and unforeseen events.
- **Labor availability and productivity:** labor shortages, skill gaps, and unpredictable weather conditions can affect labor availability and productivity.
- **Regulatory changes:** new regulations or permitting delays can introduce unforeseen costs and schedule delays.
- **Geotechnical issues:** unexpected ground conditions or environmental challenges can require additional construction efforts.

These uncertainties can lead to inaccurate cost estimates, schedule delays, and reduced project profitability. Consequently, traditional feasibility studies may provide an overly optimistic view of project risks and underrepresent the potential for project failure [7-9].

1.1. Need for Optimization in Feasibility Studies

To address the limitations of traditional feasibility studies in an uncertainty environment, incorporating optimization approaches offers significant benefits. Optimization techniques allow for the consideration of multiple project objectives and constraints simultaneously, leading to more robust and reliable project assessments. By integrating uncertainty analysis with optimization, feasibility studies can be transformed to:

- **Identify and quantify potential risks:** Uncertainty analysis techniques can be employed to identify the sources and magnitude of potential risks impacting project outcomes.
- **Develop robust project schedules:** Optimization models can be used to generate flexible schedules that can adapt to various uncertainty scenarios.
- **Optimize resource allocation:** Optimization algorithms can determine the optimal allocation of resources like labor and equipment, considering uncertainty in resource availability and costs.

- **Improve decision-making:** By providing a clearer understanding of the impact of uncertainties on project feasibility, optimization empowers stakeholders to make informed decisions at the outset [10-13] (see Figure 1).

Figure 1: Feasibility Study for Construction Projects.

This research is arranged into five sections. Section 2 defines the literature review and recent studies in area of feasibility study for construction projects and tries to show the gap in research. Section 3 suggests methodology for calculation. Section 4 proposes the results of this research. Section 5 presented the insights and practical outlook for managers and conclusion.

2. Survey of recent work

2.1. Feasibility Studies in Construction Projects

Feasibility studies are crucial for evaluating a project's viability before significant investments are made. They involve a comprehensive assessment of the project's economic, technical, operational, and legal aspects [1]. Traditional feasibility studies rely on point estimates for project costs and schedules, often leading to inaccurate assessments in an uncertain environment.

Akintoye et al. [2] highlight the importance of considering risks in feasibility studies and propose a framework incorporating risk assessment techniques. Similarly, Chan et al. [3] emphasize the need for integrating qualitative and quantitative risk analysis methods into feasibility studies for improved project decision-making.

2.2. Uncertainty Management in Construction Projects

Uncertainty management is a critical aspect of construction project management, aiming to identify, analyze, and mitigate potential risks. Various techniques are available for uncertainty management, including:

Scenario planning: This technique involves developing alternative project scenarios based on different uncertainty levels [4].

Monte Carlo simulation: This simulation technique allows for analyzing the impact of random variations in project variables on outcomes like cost and schedule [5].

Fuzzy logic: This technique handles imprecise and subjective information often encountered in uncertainty analysis [6].

2.3. Optimization Techniques in Construction Project Management

Optimization techniques have been increasingly applied in construction project management to optimize project schedules, resource allocation, and cost management. Popular optimization approaches include:

Linear Programming (LP): This technique is used to optimize project schedules under deterministic conditions by minimizing the project duration or total cost while satisfying resource constraints [7].

Integer Linear Programming (ILP): This is an extension of LP that allows for integer-valued decision variables, useful for problems like resource allocation where whole numbers of resources are required [8].

Genetic Algorithms (GA): This is a metaheuristic optimization technique inspired by natural selection that can find optimal solutions to complex problems where traditional optimization methods may struggle [9].

3. Methodology and Solution approach

This section proposes a framework for integrating uncertainty analysis and optimization into feasibility studies for construction projects.

The proposed framework consists of the following steps:

3.1. Project Definition and Data Collection

- Define project scope, activities, and dependencies.
- Collect historical data on project parameters like material costs, labor productivity, and activity durations.
- Identify potential sources of uncertainty for each parameter [15-18].

3.2. Uncertainty Analysis

- Select appropriate uncertainty modeling techniques based on the nature of uncertainties. Common approaches include:
    - Deterministic range estimates: Defining minimum and maximum values for uncertain parameters.
    - Probability distributions: Assigning probability distributions like normal or triangular distributions to represent the variability of uncertain parameters.
    - Fuzzy sets: Representing uncertainties with fuzzy membership functions that capture imprecise knowledge [18-20].

3.3. Optimization Model Development

- Formulate an optimization model that incorporates project objectives and constraints. Common objectives include minimizing project cost, duration, or resource usage. Constraints can represent limitations on resources, budgets, and regulatory requirements.
- Integrate uncertainty analysis into the model by incorporating uncertainty distributions or fuzzy sets for relevant project parameters.
- Depending on the complexity of the problem, select an appropriate optimization solver (e.g., linear programming solver, genetic algorithm) [20-23].

3.4. Scenario Generation and Optimization

- Utilize the chosen uncertainty modeling approach to generate multiple project scenarios representing different uncertainty realizations (e.g., random samples from probability distributions).
- Run the optimization model for each scenario, resulting in optimized project schedules, resource allocations, and other project outputs for each uncertainty realization [23-25].

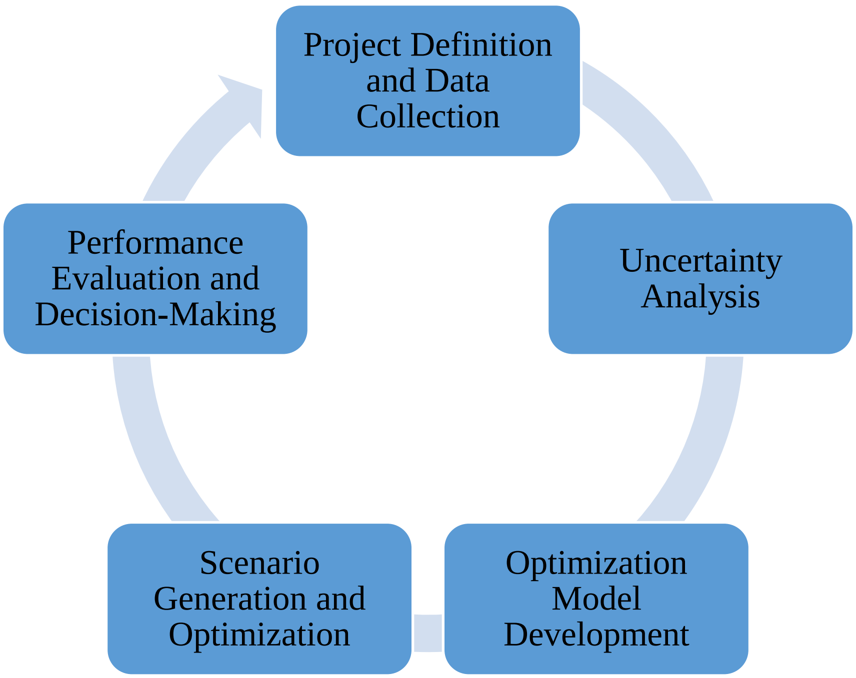

Figure 2: Methodology of this research.

3.5. Performance Evaluation and Decision-Making

- Analyze the results from scenario optimization. This may involve calculating expected values, standard deviations, or risk measures for project outcomes like cost and schedule.
- Identify robust and resilient solutions that perform well across various uncertainty scenarios.
- Translate the optimization results into actionable insights for decision-making in the feasibility study. This could involve:
  - Identifying critical uncertainties that significantly impact project outcomes.
  - Recommending strategies to mitigate risks and improve project robustness.

- Providing a more reliable assessment of project feasibility under uncertainty [25-27] (see Figure 2).

4. Results and discussion

To illustrate the framework's application, consider a project with the following simplified information

4.1. Uncertainty Modeling

- Activity durations: Model the uncertainty in activity durations using a triangular distribution with a lower bound of 90% of the deterministic estimate, a most likely value equal to the estimate, and an upper bound of 110% of the estimate.
- Material cost: Model the uncertainty in material cost using a normal distribution with a mean equal to the deterministic estimate and a standard deviation of 5% of the estimate.

4.2. Scenario Generation and Optimization

Using Monte Carlo simulation, generate a set of random samples for the uncertain parameters (activity durations and material costs) based on their respective probability distributions.

Run the optimization model for each scenario using the sampled values. The resulting solutions will provide optimized project schedules considering the variability in activity durations and material costs.

4.3. Performance Evaluation and Decision-Making (Continued)

Decision-Making Based on Optimization Results:

With the analysis from scenario optimization, the feasibility study can be enhanced by translating the results into actionable insights for decision-makers. Here's how:

- **Improved Risk Assessment:** The variability in project completion time across scenarios provides a more realistic understanding of project risks compared to traditional deterministic approaches. The standard deviation of the completion time indicates the potential deviation from the expected value due to uncertainties.
- **Identification of Critical Uncertainties:** The optimization results can highlight which uncertainties have the most significant impact on project outcomes. By analyzing the

sensitivity of the objective function (completion time) to changes in uncertain parameters, critical uncertainties can be identified. Focusing mitigation efforts on these critical uncertainties can significantly improve project robustness.

- **Developing Risk Mitigation Strategies:** Based on the identified critical uncertainties, the feasibility study can recommend strategies to mitigate their impact. This could involve:
    - **Buffer Schedules:** Adding buffer time to the critical path activities in the optimized schedule can account for potential delays due to activity duration variations.
    - **Material Cost Contingency:** Including a contingency budget in the project cost estimate can help absorb unexpected increases in material costs.
    - **Alternative Material Suppliers:** Identifying alternative suppliers for critical materials can reduce dependence on a single source and potentially mitigate cost risks.
    - **Early Contractor Involvement (ECI):** Engaging contractors early in the planning stage can leverage their expertise to identify and mitigate potential construction risks.
- **Robust Solution Selection:** By analyzing the performance of optimized solutions across various scenarios, the feasibility study can identify robust solutions that perform well under different uncertainty realizations. These solutions may involve slightly less aggressive schedules or resource allocations to provide a buffer against unexpected events.
- **More Reliable Feasibility Assessment:** By incorporating uncertainty analysis and optimization, the feasibility study provides a more comprehensive and realistic assessment of project feasibility. The potential impact of uncertainties on project outcomes is explicitly considered, leading to a more informed decision about project viability and potential risks (see Table 1-3).

Table 1: Feasibility Study for Construction Projects in Uncertainty Environment with Optimization Approach (Scenario 1)

Year	Scenario 1 (60%)			
	Fix cost	Sales revenue	Net income	Cumulative income
0	2,801,000		-2,801,000	-2,801,000
1		2,594,200	2,594,200	-206,800
2		741,200	741,200	534,400
3		370,600	370,600	905,000

Table 2: Feasibility Study for Construction Projects in Uncertainty Environment with Optimization Approach (Scenario 2)

Year	Scenario 2 (20%)			
	Fix cost	Sales revenue	Net income	Cumulative income
0	3,221,150	0	-3,221,150	-3,221,150
1	0	2,853,620	2,853,620	-367,530
2	0	815,320	815,320	447,790
3	0	407,660	407,660	855,450

Table 3: Feasibility Study for Construction Projects in Uncertainty Environment with Optimization Approach (Scenario 3)

Year	Scenario 3 (20%)			
	Fix cost	Sales revenue	Net income	Cumulative income
0	2,576,920	0	-2,576,920	-2,576,920
1	0	2,334,780	2,334,780	-242,140
2	0	667,080	667,080	424,940
3	0	333,540	333,540	758,480

Table 4: Feasibility Study for Construction Projects in Uncertainty Environment with Optimization Approach

	Scenario 1	Scenario 2	Scenario 3	Final result
Probability of occurrence	60%	20%	20%	100%
IRR	23%	19%	21%	22%
NPV	$225,179	$125,914	$153,948	$191,079

Table 4 and Figure 3-5 is presenting the financial metrics associated with different scenarios. As can be seen:

1. **Scenarios:**

   - **Scenario 1:** Probability of occurrence is 60%

- **Scenario 2:** Probability of occurrence is 20%
- **Scenario 3:** Probability of occurrence is 20%
- **Final result:** The sum of probabilities is 100%, indicating all possible scenarios are considered.

2. **Financial Metrics:**
    - **IRR (Internal Rate of Return):**
        - Scenario 1: 23%
        - Scenario 2: 19%
        - Scenario 3: 21%
        - Final result: The IRR for the overall project is calculated as 22%.
    - **NPV (Net Present Value):**
        - Scenario 1: $225,179
        - Scenario 2: $125,914
        - Scenario 3: $153,948
        - Final result: The NPV for the overall project is calculated as $ $191,079.
3. **Interpretation:**
    - The scenarios represent different possible outcomes, each with its associated probability.
    - IRR is a measure of the profitability of an investment, and the final result indicates the overall IRR considering the probabilities.
    - NPV represents the net present value of the cash flows, and the final result is the total NPV considering the probabilities.

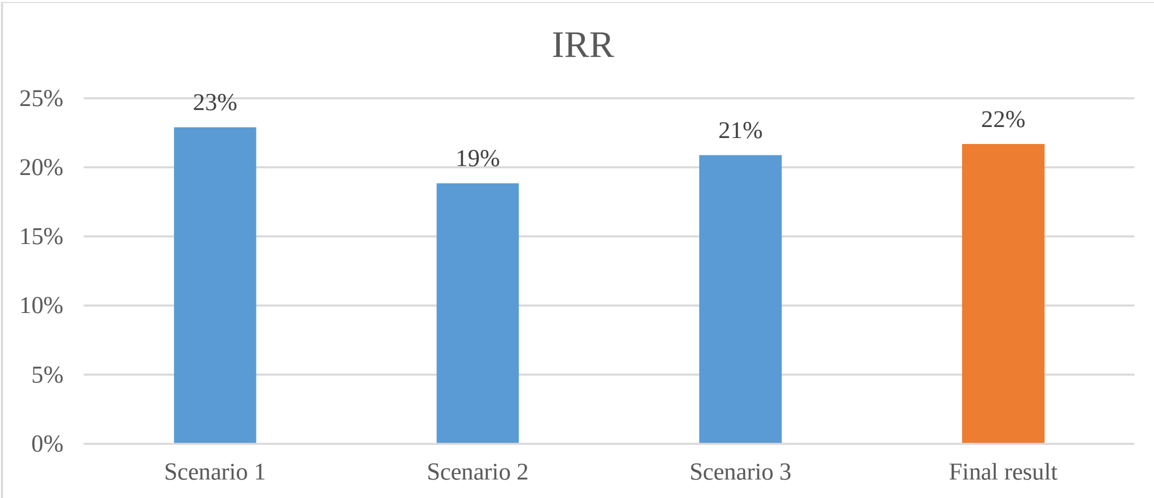

Figure 3: IRR (all scenario)

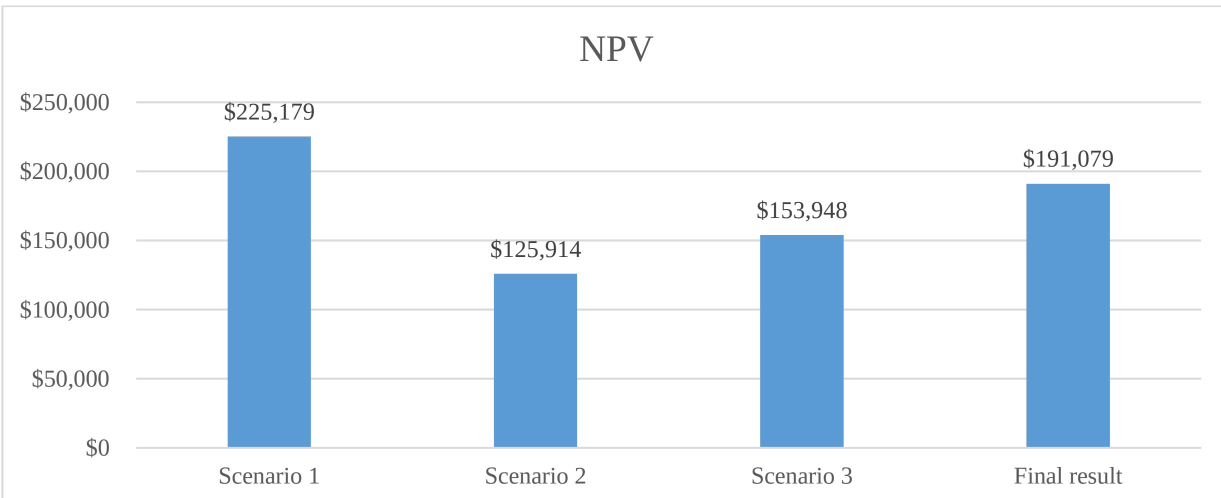

Figure 4: NPV (all scenario)

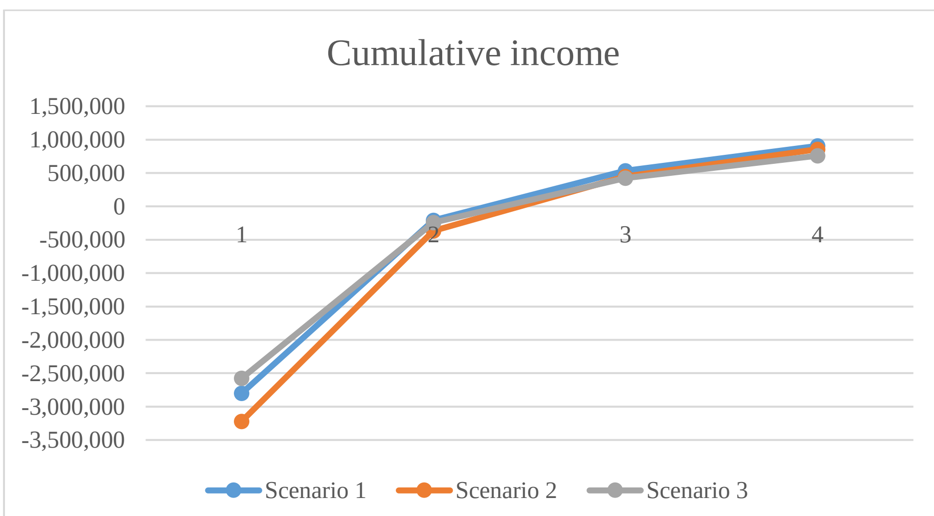

Figure 5: Cumulative income (all scenario)

In summary, this table provides a financial analysis of a project under different scenarios, taking into account the probability of each scenario occurring. The final result represents the aggregated metrics considering the likelihood of each scenario.

5. Conclusion

The proposed framework demonstrates how optimization approaches can be integrated with uncertainty analysis to enhance feasibility studies for construction projects. By considering the variability in project parameters, the framework allows for a more robust and reliable assessment of project feasibility under uncertainty. The methodology provides valuable insights for decision-making, enabling stakeholders to identify critical risks, develop mitigation strategies, and select robust solutions that can withstand unexpected challenges.

The application of optimization techniques in feasibility studies can lead to several benefits:

- **Improved Decision-Making:** By providing a clearer understanding of the impact of uncertainties on project outcomes, optimization empowers stakeholders to make informed decisions at the outset of a project.
- **Enhanced Project Feasibility:** By identifying and mitigating risks, optimization can improve the overall feasibility of a project, leading to increased success rates.
- **Increased Project Resilience:** By developing robust solutions that can adapt to various uncertainty scenarios, optimization can enhance project resilience and reduce the likelihood of cost overruns and schedule delays.

While this paper presented a simplified example, the framework can be adapted to more complex construction projects with multiple activities, resources, and uncertainties. As computational capabilities continue to advance, optimization techniques will play an increasingly crucial role in ensuring the successful execution of construction projects in an uncertain environment.

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