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An Integrated Model for Estimation of Egyptian Irrigation Canal Lining Projects based on Risk

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Abstract

Estimators encounter numerous challenges, especially when making cost and time estimates without considering risks that may face Irrigation Canal Lining Projects (ICLPs) due to insufficient and disorganized data, inadequate tools, and conventional estimation methods. This study aims to develop an integrated model for estimating ICLPs' contingency by using the Analytic Hierarchy Process (AHP) technique. This model established on two stages: First, 93 factors affecting ICLPs' contingency estimation were collected, filtered, and categorized. These factors are classified into cost, time, and risk-related factors. Then, 20 out of 93 were the most important factors affecting ICLPs' contingency estimation in Egypt. Second, The AHP model was designed on these 20 factors that represented the most important factors affecting EICLPs' contingency estimation. The developed AHP model was tested and validated using historical data from completed projects. Results showed that the predicted project contingency matches (97.42%) the average estimated contingency for real-case projects between 2021 and 2024. A user interface tool was designed using Visual Basic to facilitate the use of the final predictive model for ICLPs developers, estimators, and decision-makers.

Keywords: Canal lining, Contingency, Analytic Hierarchy Process (AHP), A user interface tool.

1. Introduction

Irrigation canal lining projects faced challenges due to the high costs, cost overruns, and delays. To address these challenges, estimators must be able to identify, evaluate, and measure the various factors related to these projects' overall cost, and time. In addition, risk assessment determines the probability and potential consequences of adverse events within a project. The anticipated impact can subsequently be factored into the project's initial estimates as a contingency [1]. There are various definitions of contingency based on the perspective of project stakeholders. Management views contingency as funds that are hoped to remain unspent and will be returned as profit upon project completion. Engineers view contingency as savings accounts that can be used to offset the extra expenses associated with project costs that are underestimated or overlooked. the construction department views contingency as a reserve meant to cover unexpected costs resulting from delayed projects, problems during construction, and lower productivity. a cost engineer views a contingency fund as a means of covering increased expenses resulting from imprecise estimations made during the estimating phase, such as underestimating the costs of labor, materials, equipment, and indirect costs. Three main categories of general project contingencies exist as 1) tolerance in the specification, 2) float in the schedule, and 3) money in the budget [2]. The contingency is determined by the estimator and top management based on the stakeholders' policy. Many estimators tend to overlook these methods and instead rely on their intuition to allocate a percentage of the cost as a contingency.

Numerous researchers have suggested various models for estimating contingency based on managing risks and uncertainties only without taking into consideration factors related to project cost, and time. In addition, ICLPs have special circumstances as water management challenges, and soil characteristics, and these models are often known for their complexity, extensive mathematical analysis, and the challenges they pose in practical application. Thus, the objective of this paper is to develop a swift and reliable model that can be utilized to estimate expected project contingency, and it is designed for Egyptian Irrigation Canals Lining Projects (EICLPs) within the national project for rehabilitating irrigation canals in Egypt for a lining type that consists of a layer of rubble stone with a specified thickness topped by a layer of plain concrete with a determined thickness using the Analytic Hierarchy Processes (AHP) technique.

2. Literature review

2.1 Contingency definitions, classifications, and methods of calculation

According to the literature, various contingency definitions, classifications, and calculation methods were backed by multiple references [3] defined contingency as the source of funding for unexpected events, and categorized it into three types depending on the project phase and the parties involved: designer contingency, contractor contingency, and owner contingency. [4] pointed out that England and Moreci (2012) defined contingency as “an amount of funds added to the base cost estimate to cover estimate uncertainty and risk exposure”. The contingency is calculated as a percentage of the estimated project cost. [5] classified contingency into two types utilized to account for the uncertainties commonly faced in engineering projects: project contingency and process contingency, and they categorized the contingency methods into two main groups: 1) Deterministic methods, and 2) Probabilistic methods. [6] mentioned three types of contingencies: Construction contingency, Design contingency, and Management contingency. [7] provided a thorough overview of contingency calculation methods, categorizing them into three main groups: deterministic, probabilistic, and modern mathematical methods; and the method of selection for estimating contingency amounts depends on various criteria, including project characteristics, complexity, usability, and desired accuracy. In addition [4, 7] outlined many studies that identified how contingency is calculated Bakhshi and Touran (2014), Baccarini (2005a), and El-Touny et al. (2014), and others; and they also mentioned 14 techniques for calculating project cost contingency: 1) Traditional percentage, 2) Expert Judgement, 3) Method of Moments, 4) Range estimating Simulation (Monte Carlo) , 5) Factor Rating, 6) Expected value, 7) Regression analysis, 8) Artificial Neural Networks, 9) Fuzzy Sets, 10) PERT, 11) Optimism Basis Uplifts, 12) Probability tree/influence diagrams, 13) Theory of Constraints, and 14) Analytical Hierarchy Process.

2.2 Contingency Estimation models in Construction Projects

Numerous models were created and developed to estimate project cost contingency by many researches as [1] developed a simple and reliable Analytic Hierarchy Process (AHP) model to identify the impact of risk factors during the bidding stages and to estimate the expected contingency cost for highway construction projects. [8] developed fuzzy-set-based model for estimating, allocating, depleting, and managing contingency fund throughout the life cycle of construction projects. [9] created a Risk-Based Cost Contingency Estimation Model (RBCCEM) to enhance the accuracy of cost contingency estimation for infrastructure projects. [10] established Artificial Natural Networks (ANN) and Regression-Based (RB) models to predict simulated cost contingency for steel reinforcement in building projects. [11] created a mathematical prediction model of the optimum cost contingency value for building projects by using the analytical hierarchy process (AHP), and the multi-attribute utility theory (MAUT) techniques. [12] used a Classification and Regression Tree (CART) model to predict the amount of project cost (PC) and cost contingency (CC) needed to cover probable cost increases at the project development stage for power plant projects. [13] developed a contingency value analysis model for construction projects that integrates cost-time risk and combines the Work Breakdown Structure (WBS) with the 80/20 (Pareto) principle creating a WBS-Pareto hybrid model. [14] developed a simple realistic Regression-based model to predict cost contingencies for road network projects.

3. Research methodology

The methodology employed in this study is outlined in 8 steps as shown in **Figure 1**.

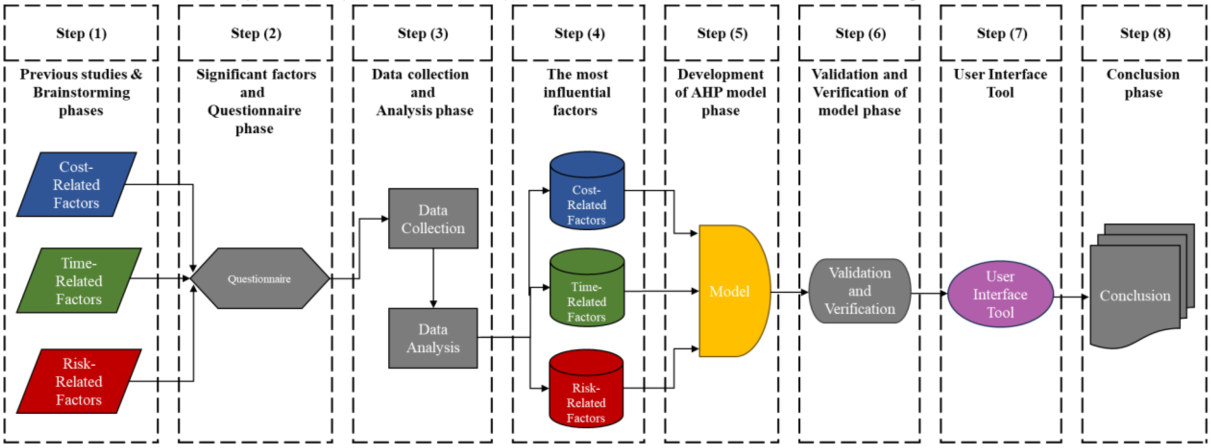


Figure 1. Representation of the research methodology.

4. Data Collection

Identifying factors related to cost, time, and risk affecting estimation of ICLPs contingency can help to accurately assess the required contingency, which should be added to the project cost estimate. These factors were identified based on the past literature review and interview with the Egyptian professionals, experts, practicing contractors, cost estimators, civil engineers, project managers, consultant, and owner involved in ICLPs through three stages. In the first and second stage, 93 factors were collected from the literature review and a brainstorming session was conducted to reduce the number of these factors and get important factors that have an impact on estimation of contingency for these projects. In the third stage, a questionnaire was used to identify the most important factors. For data collection, two questionnaires were developed. The first was developed to get the most significant factors. This questionnaire included the respondent general information and, table was prepared to be used for measuring the frequency and impact of these factors. Two key metrics were assessed on a scale of 1 to 10: 1 indicates low effectiveness, while 10 indicates high effectiveness. The first scale measured how often each component related to cost, time, and risk influenced the estimation of EICLPs' contingency, while the second scale evaluated the impact of these factors on the contingency estimates for these projects. After calculated the first two metrics, the next two indices are computed based on Frequency Index (FI), and Impact Index (II) represented by Equation **(1)**, and **(2)** [15] for all 93 factors by 150 respondents. The analysis identified 20 factors out of 93 factors were the most important factors influencing the estimation of EICLPs' contingency along with their frequencies and impacts as detailed in **Table 1**.

$$\boldsymbol{Frequency\ Index\ (FI)} = \frac{\sum_{i=1}^{n} F_i}{a \times n} \quad \textbf{(1)}$$

$$\boldsymbol{Impact\ Index\ (II)} = \frac{\sum_{i=1}^{n} I_i}{a \times n} \quad \textbf{(2)}$$

where

$\sum_{i=1}^{n} F_i$ total frequency scores of each factor from the respondents

$\sum_{i=1}^{n} I_i$ total impact scores of each factor from the respondents

the scoring ranges from 1 to 10

n the total number of participating respondents is 150

a the upper scale for each measure equals 10

Table 1. The 20 most important factors affecting the estimation of EICLPs' contingency and their frequencies and impacts.

Categories / Subcategories	**Frequency Index (FI)**	**Impact Index (II)**
Cost-Related Factors		
Design-Related Factors		
Area of irrigation canals' cross-section [Hydraulic cross-sectional area] (m^2)	0.3267	0.3260
Area of irrigation canals' cross-section with plain concrete lining (m^2)	0.3200	0.3273
Irrigation canals lining length (m run)	0.3147	0.3113
Area of irrigation canals' cross-section with rubble stone lining (m^2)	0.2960	0.3033
Construction-Related Factors		
Pouring works of plain concrete mortar consisting of (gravel, sand, cement, and water) for irrigation canals' beds, side slopes, and feet	0.3320	0.3433
Construction works of rubble stones for irrigation canals' beds, side slopes, and feet	0.3167	0.2967
Irrigation canals' survey works such as (reshaping, levels' adjustments…)	0.3440	0.2500
Overheads-Related Factors		
Equipment expenses as (leased equipment, owned equipment, and maintenance and repairs)	0.3187	0.3013
Time-Related Factors		
Owner-Related Factors		
Owner's payment policy (such as Initial payment and invoices)	0.3240	0.3280
Contractor-Related Factors		
Financing sources for irrigation canals lining projects	0.2720	0.3080
Project-Related Factors		
Water turn rotation in irrigation canals (on and off turns)	0.3333	0.3373
Labor productivity participating in irrigation canals lining projects	0.3173	0.3413
Efficiency of irrigation canals' surveying works that need to be lined	0.3180	0.2993
Productivity of plain concrete mixer in site used for pouring beds, side slopes, and feet for irrigation canals that required lining them	0.3060	0.3087
Equipment efficiency used in the execution of irrigation canals lining works	0.3067	0.3053
Risk-Related Factors		
Technical Risk-Related Factors		
Lack of sufficiently skilled and trained labor	0.3000	0.3020
Environmental Risk-Related Factors		
Effects of irrigation canals lining projects on plant and animal life	0.2840	0.2933
Financial Risk-Related Factors		
Inaccurate project cost estimate	0.3007	0.3207
High costs of materials and equipment needed for irrigation canals lining works	0.2727	0.3247
Social Risk-Related Factors		
Create local jobs opportunities and improve the economic conditions of the region	0.2760	0.2920

5. Development of project contingency model

In this study, the AHP model was applied to determine project contingency. [11] defined AHP is an analytical tool that deals with multi-criteria decision-making (MCDM) problems by which decision-makers can set priorities through a series of pairwise comparisons. Also, they pointed out that AHP was introduced by Thomas Saaty in 1980 as a key method in making decisions by combining rational and intuitive elements with the selection of an optimum alternative from several alternatives based on several criteria. It allows pairwise comparisons to set priorities of choices and examine the inconsistencies in judgments so that a basis for improvement in consistency will be provided. The following are the basic steps followed in conducting the proposed AHP project contingency model:

Step (1): Define the goal: To estimate project contingency for EICLPs.

Step (2): Identify all pertinent criteria: Relevant criteria cost, time, and risk-related factors impacting the project contingency estimation for EICLPs were identified following the research methodology. Subsequently, the key relevant factors were used to gather data for testing the suggested project contingency model. The data were collected from 150 Egyptian experts and construction projects participants out of a mix of online, physical, and phone interviews using a pre-existing questionnaire. The project budgets varied from 2.5 to 320 million Egyptian pounds, with durations ranging from 5 months to 1 year.

Step (3): Creation of hierarchy structure: The criteria are organized into a hierarchy that descends from a primary objective to different criteria, sub-criteria (1), and sub-criteria (2) across subsequent levels as shown in **Figure 2**.

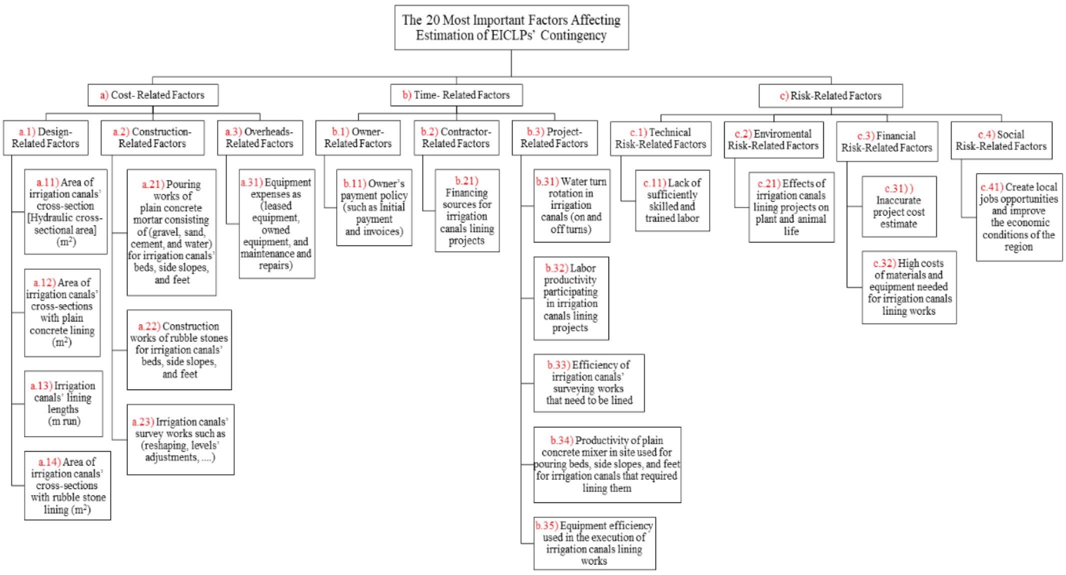


Figure 2. Hierarchy of the 20 most important factors affecting the estimation of EICLPs' contingency and their criteria, sub-criteria (1), and sub-criteria (2).

Step (4): Construction of comparison matrix: The comparison matrix is constructed using Saaty's 1-9 scale of relative importance. The proposed numerical nine-point scale was used to evaluate factors by Saaty (1988), with 1 indicating equal importance and 9 extreme importance [11]. It is a dimensional square matrix formed by factors. The diagonal elements of the matrix are all equal to one since they signify comparing a criterion with itself. The values in the lower triangle are reciprocals of those in the upper triangle (i.e. aij = 1/aji). All values in the matrix are positive.

Step (5): Compute priority weights and criteria ratings: The priority weights for structured criteria are established through pairwise comparisons utilizing a questionnaire to reflect various decision-makers assessments and relative preferences. When evaluating each pair of criteria, the decision maker must answer a question like "How important is criterion A compared to criterion B, and by how much on a scale of 1 to 9?". Weights can differ among individuals. For multiple criteria layers, weights for higher-level criteria are computed first and then applied to lower-level criteria (composite weights). This process continues down through the hierarchy, establishing composite weights for subsequent levels.

Step (6): Data collection for project contingency model: The second questionnaire was created for the Analytic Hierarchy Process (AHP) technique to gather project information. It consisted of two parts. Part, one gathered general information about the respondent. In part two, a comparison was made between criteria, sub-criteria (1), and sub-criteria (2) to determine the ratio among parameters of project contingency calculated using Equation **(3)**.

$$\boldsymbol{Priority\ Vector = Total\ Weight\ from\ respondents\ /N} \quad (3)$$

Where: N= Number of Respondents; (N=120), and a summary of priorities of criteria and sub-criteria resulting from the 120 interviews' collected data are presented in **Table 2**, the analysis shows the weight of all categories.

Table 2. Summary of the criteria and sub-criteria priorities based on data collected from 120 interviews.

	Categories	**Total Weight**	**Priority Vector**
a)	**Cost-Related Factors**	40.873	0.3406
b)	**Time-Related Factors**	26.131	0.2178
c)	**Risk-Related Factors**	52.996	0.4416
a)	**Cost-Related Factors**		
a.1)	Design-Related Factors	51.069	0.4256
a.2)	Construction-Related Factors	40.240	0.3353
a.3)	Overheads-Related Factors	28.692	0.2391
a.1)	**Design-Related Factors**		
a.11)	Area of irrigation canals' cross-section [Hydraulic cross-sectional area] (m^2)	45.053	0.3754
a.12)	Area of irrigation canals' cross-section with plain concrete lining (m^2)	29.048	0.2421
a.13)	Irrigation canals lining length (m run)	30.388	0.2532
a.14)	Area of irrigation canals' cross-section with rubble stone lining (m^2)	15.512	0.1293
a.2)	**Construction-Related Factors**		
a.21)	Pouring works of plain concrete mortar consisting of (gravel, sand, cement, and water) for irrigation canals' beds, side	52.776	0.4398
a.22)	Construction works of rubble stones for irrigation canals' beds, side slopes, and feet	19.820	0.1652
a.23)	Irrigation canals' survey works such as (reshaping, levels' adjustments…)	47.404	0.3950
a.3)	**Overheads-Related Factors**		
a.31)	Equipment expenses as (leased equipment, owned equipment, and maintenance and repairs)	120	1
b)	**Time-Related Factors**		
b.1)	Owner-Related Factors	56.529	0.4711
b.2)	Contractor-Related Factors	23.316	0.1943
b.3)	Project-Related Factors	40.155	0.3346
b.1)	**Owner-Related Factors**		
b.11)	Owner's payment policy (such as Initial payment and	120	1
b.2)	**Contractor-Related Factors**		
b.21)	Financing sources for irrigation canals lining projects	120	1
b.3)	**Project-Related Factors**		
b.31)	Water turn rotation in irrigation canals (on and off turns)	33.498	0.2791
b.32)	Labor productivity participating in irrigation canals lining	28.877	0.2406
b.33)	Efficiency of irrigation canals' surveying works that need to be lined	23.495	0.1958
b.34)	Productivity of plain concrete mixer in site used for pouring beds, side slopes, and feet for irrigation canals that required	15.957	0.1330
b.35)	Equipment efficiency used in the execution of irrigation canals lining works	18.173	0.1514
	Categories	**Total**	**Priority**
c)	**Risk-Related Factors**		
c.1)	Technical Risk-Related Factors	25.466	0.2122

c.2)	Environmental Risk-Related Factors	38.866	0.3239
c.3)	Financial Risk-Related Factors	44.184	0.3682
c.4)	Social Risk-Related Factors	11.483	0.0957
c.1)	**Technical Risk-Related Factors**		
c.11	Lack of sufficiently skilled and trained labor	120	1
c.2)	**Environmental Risk-Related Factors**		
c.21)	Effects of irrigation canals lining projects on plant and animal life	120	1
c.3)	**Financial Risk-Related Factors**		
c.31)	Inaccurate project cost estimate	19.557	0.1630
c.32)	High costs of materials and equipment needed for irrigation canals lining works	100.443	0.8370
c.6)	**Social Risk-Related Factors**		
c.61)	Create local jobs opportunities and improve the economic conditions of the region	120	1

The analysis shows the distribution of weight across various categories. It illustrates the weights of primary project contingency categories: Cost-related factors at 34.06%, Time-related factors at 21.78%, and Risk-related factors at 44.16% as depicted in **Figure 3-a**, **Figure 3-b** represents the weights of the main Cost-related factors: Design-related factors at 42.56%, Construction-related factors at 33.53%, and Overheads-related factors at 23.91%, **Figure 3-c** shows that the weights of main Time-related factors: Owner-related factors at 47.11%, Contractor-related factors at 19.43%, and Project-related factors at 33.46%, and **Figure 3-d** exhibits the weights of main Risk-related factors: Technical risk-related factors at 21.22%, Environmental risk-related factors at 32.39%, Financial risk-related factors at 36.82%, and Social risk-related factors at 9.57%.

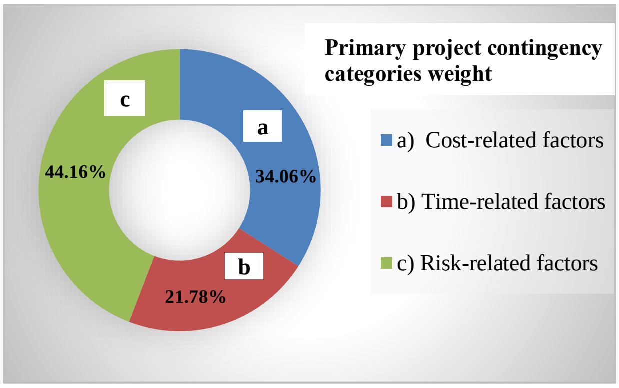


Figure 3-a. The average weight of primary criteria.

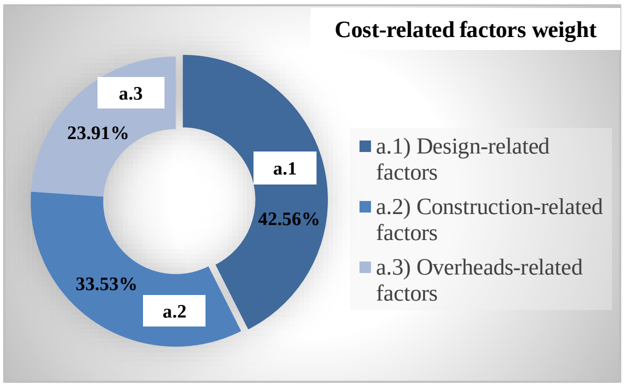
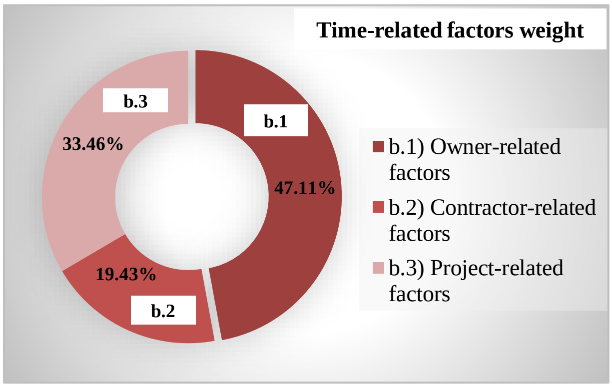


Figure 3-b. The average weight of sub-criteria (1) for Cost-related factors.



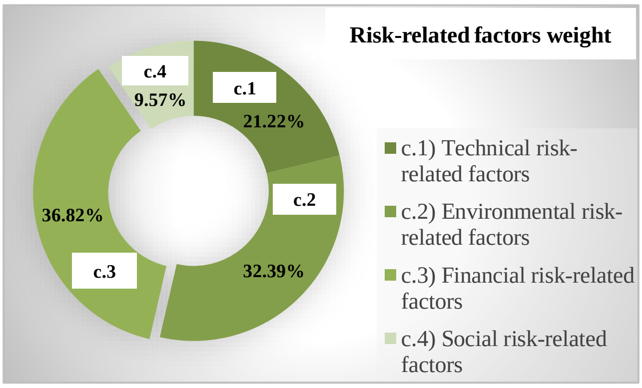


Figure 3-c. The average weight of sub-criteria (1) for Time-related factors.

Figure 3-d. The average weight of sub-criteria (1) for Risk-related factors.

Step (7): Project contingency (P_C) Model Development: After establishing the weights of each factor in the hierarchy, the project contingency (Pc) is calculated using the model depicted in Equation **(4)** [1].

$$\boldsymbol{Project\ contingency\ (P_C)} = \sum_{i=1}^{n} W_i \times FI_i \times II_i \quad \textbf{(4)}$$

Where Wi represents the relative weight of factor i, relative to the weight of its category as illustrated in. displays the weights and relative weights of criteria, sub-criteria (1), and sub-criteria (2). It also presents the calculation for project contingency, derived from the total of (relative weight multiplied by the frequency index and impact index for each criterion).

Table 3 shows that project contingency constitutes 9.43% of the project cost. As a result, the project estimator must allow for nearly a 9.43% escalation in project costs attributable to factors affecting the estimation of EICLPs' contingency. This estimation pertains to the presence of all factors. The scenario may vary depending on the expected number of factors that occur. In such instances, the project contingency value may be changed.

Table 3. Summary of criteria and sub-criteria priorities for 120 interviews' data and project contingency calculation.

Criteria	**Weight**	**Sub-Criteria (1)**	**Weight**	**Sub-Criteria (2)**	**Weight**	**Relative Weight**	**Frequency Index (FI)**	**Impact Index (II)**	**Project Contingency (Pc)**
Cost-Related Factors	0.3406	Design-Related Factors	0.4256	Area of irrigation canals' cross-section [Hydraulic cross-	0.3754	0.0544	0.3267	0.3260	0.0058
				Area of irrigation canals' cross-section with plain concrete	0.2421	0.0351	0.3200	0.3273	0.0037
				Irrigation canals lining length (m run)	0.2532	0.0367	0.3147	0.3113	0.0036
				Area of irrigation canals' cross-section with rubble stone	0.1293	0.0187	0.2960	0.3033	0.0017
		Construction-Related Factors	0.3353	Pouring works of plain concrete mortar consisting of (gravel, sand, cement, and water) for irrigation	0.4398	0.0502	0.3320	0.3433	0.0057
				Construction works of rubble stones for irrigation canals'	0.1652	0.0189	0.3167	0.2967	0.0018
				Irrigation canals' survey works such as (reshaping, levels'	0.3950	0.0451	0.3440	0.2500	0.0039
		Overheads-Related Factors	0.2391	Equipment expenses as (leased equipment, owned equipment, and maintenance and	1.0000	0.0814	0.3187	0.3013	0.0078
Time-Related Factors	0.2178	Owner-Related Factors	0.4711	Owner's payment policy (such as Initial payment and invoices)	1.0000	0.1026	0.3240	0.3280	0.0109

		Contractor-Related Factors	0.1943	Financing sources for irrigation canals lining projects	1.0000	0.0423	0.2720	0.3080	0.0035
		Project-Related Factors	0.3346	Water turn rotation in irrigation canals (on and off turns)	0.2791	0.0203	0.3333	0.3373	0.0023
				Labor productivity participating in irrigation canals lining	0.2406	0.0175	0.3173	0.3413	0.0019
				Efficiency of irrigation canals' surveying works that	0.1958	0.0143	0.3180	0.2993	0.0014
				Productivity of plain concrete mixer in site used for pouring beds, side slopes, and feet for irrigation canals	0.1330	0.0097	0.3060	0.3087	0.0009
				Equipment efficiency used in the execution of irrigation canals	0.1514	0.0110	0.3067	0.3053	0.0010
Risk-Related Factors	0.4416	Technical Risk-Related	0.2122	Lack of sufficiently skilled and trained	1.0000	0.0937	0.3000	0.3020	0.0085
		Environmental Risk-Related Factors	0.3239	Effects of irrigation canals lining projects on plant and animal	1.0000	0.1430	0.2840	0.2933	0.0119
		Financial Risk-Related Factors	0.3682	High costs of materials and equipment needed for	0.8370	0.1361	0.3007	0.3207	0.0026
				Inaccurate project cost estimate	0.1630	0.0265	0.2727	0.3247	0.0120
		Social Risk-Related Factors	0.0957	Create local jobs opportunities and improve the economic	1.0000	0.0423	0.2760	0.2920	0.0034
Project Contingency (Pc) =$\sum_{i=1}^{n} W_i \times FI_i \times II_i$									**0.0943**

Figure 4 depicts that the project contingency weight for each factor relative to the total project contingency weight of 12 factors represented 85.58%. The highest impact was seen in the (High costs of materials and equipment needed for irrigation canals lining works) at 12.73%. This was followed by (Effects of irrigation canals lining projects on plant and animal life) at 12.62%, (Owner's payment policy (such as Initial payment and invoices)) at 11.56%, (Lack of sufficiently skilled and trained labor) at 9.01%, (Equipment expenses as (leased equipment, owned equipment, and maintenance and repairs)) at 8.27%, (Area of irrigation canals' cross-section [Hydraulic cross-sectional area] (m^2)) at 6.15%, (Pouring works of plain concrete mortar for irrigation canals' beds, side slopes, and feet) at 6.04%, (Irrigation canals' survey works such as (reshaping, levels' adjustments…) at 4.14%, (Area of irrigation canals' cross-section with plain concrete lining (m^2)) at 3.92%, (Irrigation canals lining length (m run)) at 3.82%, (Financing sources for irrigation canals lining projects) at 3.71%, (Create local jobs opportunities and improve the economic conditions of the region) at 3.61%, and other factors at 14.42%.

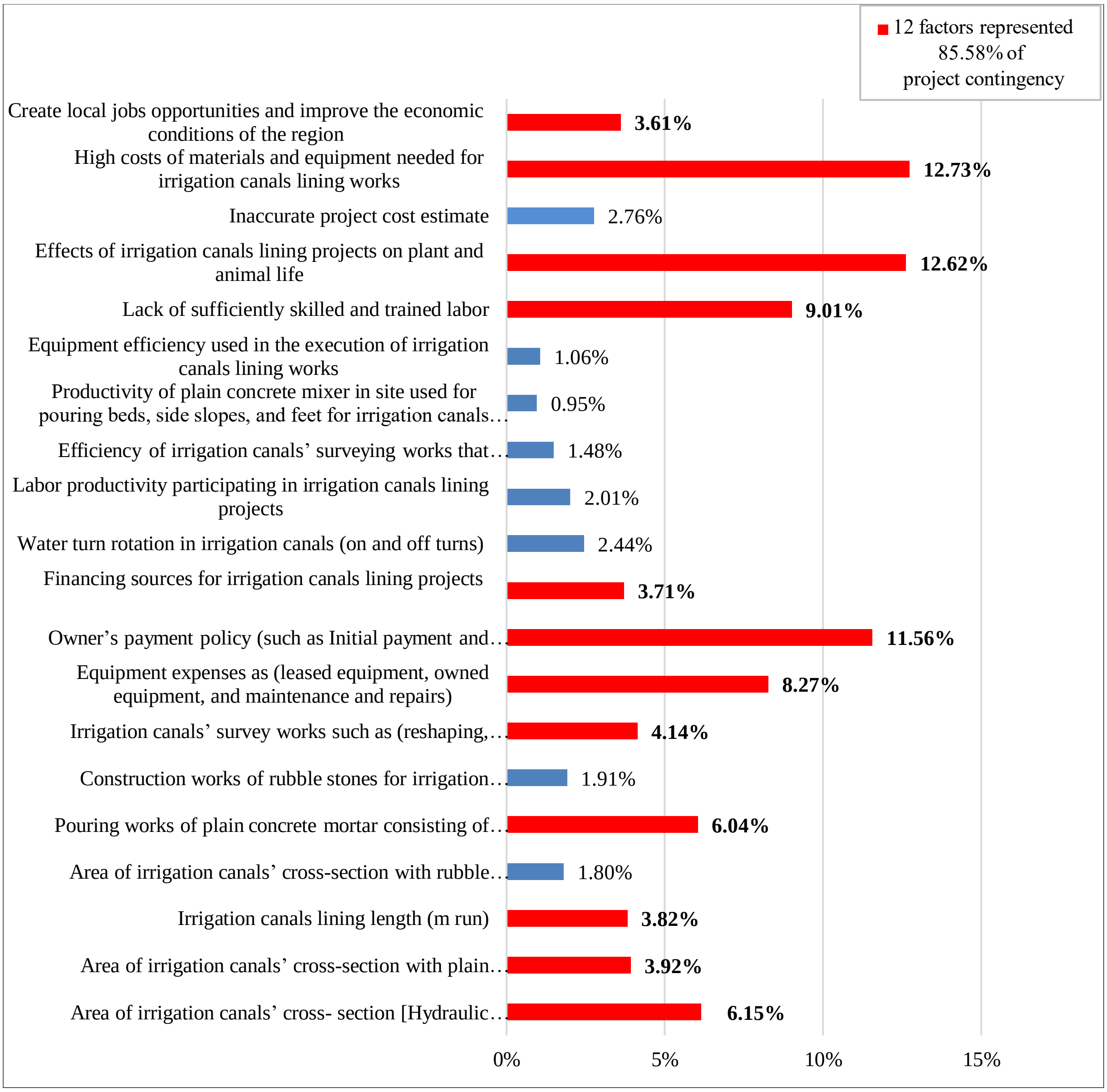


Figure 4. The weight of each factor is relative to the project contingency weight.

6. Validation of model

The project contingency model was tested using data from eight Egyptian irrigation canal lining projects to validate its accuracy. By comparing estimated and actual costs, unexpected additional costs were calculated and the actual project contingency was determined, ranging from 2.48% to 23.20% across the projects as depicted in **Table 4**. The average project contingency from the data (9.68%) closely matched the estimated average project contingency from the model (9.43%). This validation of the model's accuracy provides valuable insights for project managers and stakeholders, enabling them to anticipate better and manage potential cost overruns.

Table 4. Cost overrun and contingency analysis for eight EICLPs.

Project No.	Total estimated cost (LE)	Actual cost (LE)	Cost overrun (LE)	Project contingency (%)
P1	2,899,456	2,971,252	71,796	2.48%
P2	7,753,550	7,961,542	207,992	2.68%

P3	14,885,471	15,417,792	532,321	3.58%
P4	3,740,000	3,971,390	231,390	6.19%
P5	76,006,143	84,574,034	8,567,891	11.27%
P6	10,920,000	12,163,620	1,243,620	11.39%
P7	5,074,600	5,921,555	846,955	16.69%
P8	9,907,350	12,206,263	2,298,913	23.20%
	Average project contingency (%)			**9.68%**

7. Project contingency prediction model software application

A software program has been created using Net Framework, Visual Basic, and algorithm coding to integrate the features and functions of this model. This tool aims to assist ICLPs' stakeholders in calculating the project contingency value, which is added to the estimated project cost to achieve a more accurate and reliable estimate. The software, named the Project Contingency Prediction App for ICLPs in Egypt has a user interface with five split screens as the first screen serves as the main interface as depicted in **Figure 5-a**, while the second, third, and fourth screens present factors related to cost, time, and risk, including their Relative Weight (Wi), Frequency Index (FI), and Impact Index (II) as shown in **Figure 5-b**, **Figure 5-c**, and **Figure 5-d**. The final screen shows the final predicted project contingency value for ICLPs as depicted in **Figure 5-e**.

Figure 5-a. Start Up Screen.

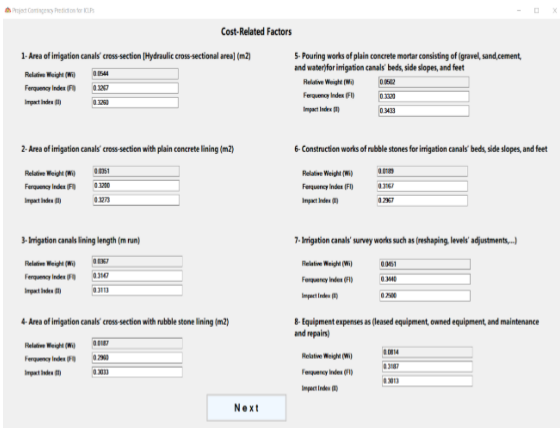


Figure 5-b. Cost-Related Factors Input Data Screen.

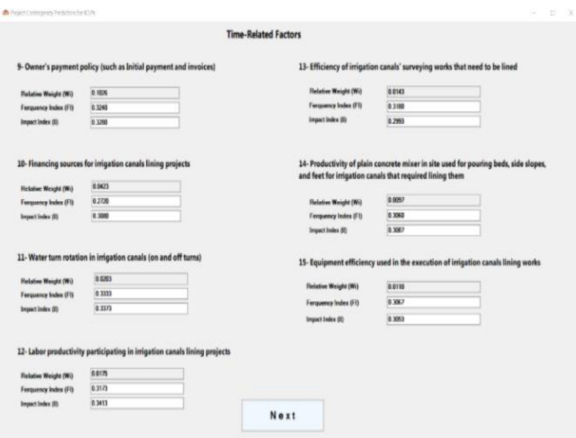


Figure 5-c. Time-Related Factors Input Data Data Screen.

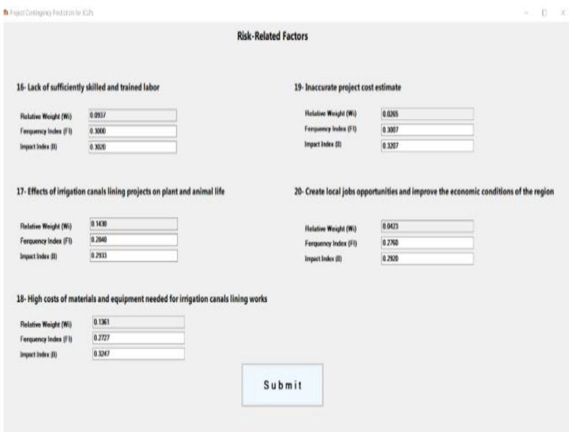


Figure 5-d. Risk-Related Factors Input Screen.

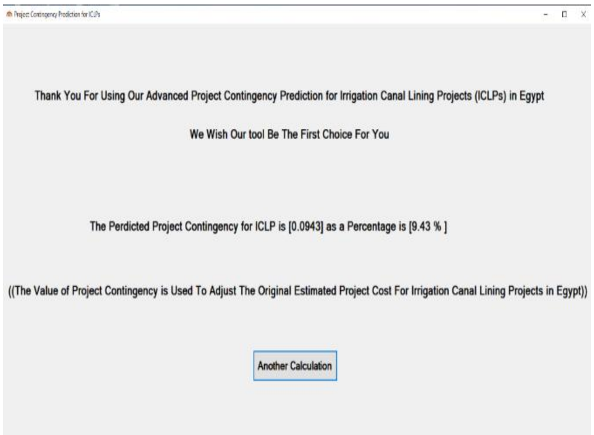


Figure 5-e. The Predicted Project Contingency Screen.

8. Conclusions

This study aimed to develop an integrated model for estimating ICLPs' contingency by using the Analytic Hierarchy Process (AHP) technique within the national project for rehabilitating irrigation canals in Egypt. In this research, two surveys were conducted by 150 and 120 participants, respectively, from Egyptian experts and construction companies in this field to evaluate these factors. It focused on a common lining type of rubble stone with a specific thickness, covered by a layer of plain concrete with a set thickness used in these projects. Each factor of 93 factors was identified and grouped for each part into 25 factors related to project cost were categorized into 3 groups (Design, Construction, and Overheads)-related factors; 30 factors related to project time were categorized into 3 groups (Owner, Contractor, and Project)-related factors; and 38 factors related to risk categorized into 6 groups (Technical, Environmental, Financial, Operational, Legal and regulatory, and Social) risk-related factors. As a result, the 20 most important factors out of 93 factors: 8 out of 25 factors related to project cost, 7 out of 30 factors related to project time, and 5 out of 38 factors related to risk affecting the estimation of ICLPs' contingency to achieve success of completing irrigation canal lining projects have been identified. The 20 most important factors utilized in developing an integrated and simplified model using Analytic Hierarchy Processes (AHP) to analyze and estimate the project contingency for EICLPs. The developed model was tested using historically completed projects. It has been observed that project contingencies varied between 2.48% and 23.2%. The average project contingency across the eight projects stands at 9.68%, a figure close to the model-derived value of 9.43%. The findings indicate a strong correlation (97.42%) between predicted and actual project contingency, affirming the model's predictive accuracy for Project Contingency. The final model for predicting the project contingency for ICLPs in Egypt is ready for use. As a result, the proposed model could be a valuable tool for ICLPs estimators. In summary, the study emphasizes the value of adopting structured, data-driven approaches to address uncertainties in large-scale infrastructure projects. Besides its role as a tool for estimating contingencies in irrigation canal lining projects ICLPs, the research establishes a solid foundation for improving estimation practices in similar projects that demand precision in planning and resource management. the proposed model is a practical tool for current applications and a stepping stone toward future improvements in estimating and managing construction contingencies. It holds a significant promise for enhancing the success of irrigation canal lining projects and similar endeavors in the construction sector.

Future studies can build on this work by investigating alternative methods for estimation, such as using artificial intelligence, to achieve even greater accuracy. Moreover, incorporating digital construction technologies like advanced data analytics could make the model more versatile, allowing for real-time contingency estimation and management. Such advancements have the potential to reshape the management of water infrastructure projects, and driving improvements in efficiency and decision-making.

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