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MULTI-PARAMETER OPTIMIZATION OF CONSTRUCTION DURATION IN MONOLITHIC REINFORCED CONCRETE SYSTEMS USING COMPOSITE INDICATORS

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Abstract- In the Azerbaijani construction industry, the strategic organization of high-rise monolithic reinforced concrete projects is a top priority. Experts are increasingly focused on achieving superior scheduling efficiency to ensure that these structural works are finalized within strictly defined periods. The complexity of numerous organizational and technological factors influencing the execution of monolithic RC structural processes makes it crucial to control and study these processes scientifically. The problem of resource allocation and technological sequence optimization should be resolved since delays at different stages of the project lengthen the construction period. For this objective, the use of complex indicators enables more accurate planning by providing an integrated assessment of project duration, resource consumption, and technological quality. The study included the construction of a mathematical model of a complex indicator, parameter analysis, and expert assessment to optimize the duration of work on the installation of monolithic reinforced concrete. The results established a linear mathematical model (y=113.904t+143.9) that quantifies the composite impact of twelve key parameters. The findings demonstrate that optimizing organizational factors, such as formwork turnover and site supervision, can significantly stabilize the construction timeline in the Azerbaijani building sector.

Keywords: Monolithic Reinforced Concrete, Organizational Technological Factors, Complex İndicator, Optimization, Mathematical Model, Construction Period, Expert Assessment.

1. INTRODUCTION

The competitiveness and quality of building product is directly related to the management of production processes, that is, if work is completed on time, with low resource costs, and with high quality.

In recent years, monolithic reinforced concrete systems have become widely used in the construction of multi-story residential and public buildings in Azerbaijan. According to statistical data, 85-90% of housing construction is carried out based on this structure. This circumstance makes it especially crucial to plan the installation of monolithic reinforced concrete more effectively, both technologically and organizationally.

In practice, taking organizational and technological elements into account together has proven advantageous, despite the fact that their effects on the building process vary. The construction procedures of multi-story monolithic reinforced concrete buildings are complicated, influenced by numerous organizational and technological elements. Factors such as the technologies used in monolithic reinforced concrete work also have an impact: the use of automated systems, frequent replacement of formwork systems, the use of new equipment and mechanisms, as well as weather and climatic conditions [1, 2, 6]. This shows that assessing the factors influencing the resolution of organizational and technological issues related to the installation of monolithic reinforced concrete is complex and comprehensive process. Therefore, it is necessary to examine several approaches in order to determine the elements that affect organizational and technological indicators [3, 5].

Monolithic reinforced concrete production involves several labor-intensive, resource-intensive steps, including formwork removal, concrete maintenance, reinforcing, and concreting. At each point, delays and inconsistencies extend construction time and the building process, raise expenses, and eventually lower quality. Therefore, effective planning of process sequences, resource allocation, and technical flows are essential for optimizing the timing of work [9, 11].

It is crucial to use complex indicators to ensure that optimization is based on scientific principles. This indicator allows for more accurate planning and management, assessing the duration of work, labor, and financial costs, as well as technological quality. At the same time, enhancing organizational and technical reliability (OTR) is crucial. OTR ensures the stable and uninterrupted operation of the construction process in the face of random failures and unexpected delays.

As a result, optimizing the duration of monolithic reinforced concrete works and using a complex indicator improves overall construction efficiency, reduces resource and time losses, justifies management decisions,

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and, ultimately, improves construction product quality. This research contributes significantly to the long-term progress of Azerbaijan's building sector by integrating cutting-edge administrative methodologies and sustainable operational practices [13, 14, 17]. Furthermore, recent studies highlights that the optimization of construction schedules and the effective management of risks in high-rise building projects are essential for ensuring overall project reliability [18, 19].

While existing literature offers general frameworks for construction optimization, there is a lack of specialized models tailored to the specific regulatory and technical landscape of Azerbaijan. This study bridges this gap by adapting advanced weighting methodologies to the national construction standards, providing a localized decision-support tool for high-rise projects.

In order to streamline the construction timelines associated with monolithic reinforced concrete frameworks in high-rise residential projects, following comprehensive organizational-technological framework proposed by Stepanov [20], a systematic identification of complex indicators is essential to determine complex indicators, select a method for calculation, and formulate optimisation algorithms. It is crucial to consider complex indicators, including project duration, resource efficiency, quality indicators, and risk factors [4].

This chapter of the scientific research work is devoted to the formulation and development of a mathematical model utilizing the fundamental principles of complex indicator assessment derived from recent research [20], for calculating the complex indicator (CI_{optim}) for optimising the duration of monolithic reinforced concrete works in residential buildings. To accomplish this, previously determined parameters were analysed and processed, gathering enough experimental data based on established research databases [20]; the required mathematical model was identified, its analysis was carried out, and its impact on previously determined factors was assessed. At this time, complex indicators were assessed through expert surveys [7, 10].

2. RESEARCH METHODOLOGY: EXPERT ASSESSMENT

The key challenge and task when applying the expert assessment method is to determine the necessary number of experts involved. Based on this, an appropriate methodology can be used to determine the required number of experts [16]. The minimum number of specialists required for the assessment is established through Equation (1):

$$m = \left(\frac{t\sigma}{M}\right)^2 \tag{1}$$

where σ represents the root mean square error (RMSE); m signifies the total count of experts, while M indicates the standard error associated with the average value.

According to research, when applying the expert assessment method for different values of the variation coefficients, mean errors, and probability coefficients, the maximum spread rarely exceeds 50%. Data are calculated at $V = 50\%$.

The number of experts was 70, and they were split up into seven groups of ten. The selection criteria for the 70 experts included a minimum of 10 years of professional experience in high-rise construction and holding senior engineering or management positions. This high level of collective expertise ensures that the subjective ratings reflect real-world technical constraints in the Azerbaijani construction sector. The panel consisted of seasoned industry practitioners with extensive building sector backgrounds and executive directors from regional engineering firms. A questionnaire was provided to the experts to conduct the assessment. To facilitate the study, a structured survey instrument was disseminated among the professional panel. Following the data collection phase, the level of consensus within the specialists' collective feedback was meticulously analyzed to establish statistical reliability [12].

For this, it is necessary to use the assessment of the degree of compliance based on the Kendall coefficient (W) [8, 9, 10].

The value of the Kendall coefficient is determined according to Equation (2):

$$W = \frac{12S}{n^2\left(m^3 - m\right)} \tag{2}$$

In this context, S represents the aggregate squared deviations of the expert scores from the mean value; n signifies the total number of specialists, and m indicates the count of evaluation objects.

The Kendall coefficient is bounded within a numerical range of 0 to 1; hence, elevated outcomes signify a more robust consensus among the participating specialists.

Upon performing the quantitative assessment, a resulting value of W=1.0 was obtained, signifying a total alignment of professional perspectives.

Following the identification of critical factors and the requisite panel of specialists who collectively impact the multi-faceted duration optimization metric for monolithic reinforced concrete work (CI_{optim}), an analytical correlation study was conducted to examine the interplay between the specified variables.

The primary purpose of correlation analysis is to evaluate the degree of association between random parameters that impact the installation procedure for monolithic constructions.

To evaluate the degree of interaction between the identified parameters, the Pearson correlation coefficient is utilized as defined in Equation (3):

$$r_{xy} = \frac{\sum(x_i - x).(y_i - y)}{\sqrt{\sum(x_i - x)^2.\sum(y_i - y)^2}} \tag{3}$$

where x_i and y_i represent the accepted values for variables x and y, respectively. In this context, x denotes the arithmetic mean for variable x, while y signifies the arithmetic mean for variable y.

After completing the calculations, let's calculate the pairwise correlation coefficients using the given values and summarize the results obtained in Table 1.

Table 1. Intercorrelation matrix of variables

	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}
X_1	1.0	0.183	0.162	0.274	0.094	0.213	0.118	0.247	0.137	0.221	0.176	0.143
X_2	0.147	1.0	0.241	0.108	0.263	0.097	0.219	0.284	0.208	0.172	0.143	0.251
X_3	0.192	0.202	1.0	0.174	0.298	0.287	0.131	0.158	0.219	0.168	0.308	0.188
X_4	0.232	0.134	0.142	1.0	0.043	0.271	0.152	0.261	0.127	0.139	0.248	0.112
X_5	0.107	0.293	0.321	0.060	1.0	0.197	0.153	0.231	0.194	0.228	0.224	0.219
X_6	0.172	0.052	0.246	0.291	0.215	1.0	0.253	0.103	0.182	0.027	0.128	0.084
X_7	0.086	0.245	0.089	0.181	0.108	0.211	1.0	0.149	0.178	0.158	0.172	0.254
X_8	0.270	0.237	0.178	0.276	0.199	0.124	0.175	1.0	0.108	0.219	0.227	0.331
X_9	0.151	0.177	0.184	0.147	0.208	0.135	0.197	0.136	1.0	0.281	0.132	0.297
X_{10}	0.173	0.187	0.183	0.151	0.197	0.056	0.113	0.181	0.308	1.0	0.124	0.243
X_{11}	0.188	0.102	0.335	0.204	0.189	0.150	0.126	0.184	0.097	0.087	1.0	0.072
X_{12}	0.103	0.271	0.203	0.080	0.178	0.052	0.212	0.346	0.250	0.208	0.091	1.0

The Chaddock scale provides the following interpretation for the correlation coefficient (r): thresholds between 0 and 0.3 represent a negligible relationship, while the interval from 0.3 to 0.5 indicates a weak connection. For coefficients spanning $0.5 < r < 0.7$, the correlation is deemed moderate. Values within the 0.7 to 0.9 range signify a robust association, and any result exceeding the 0.9 mark (up to 1.0) is classified as an exceptionally high correlation.

The intercorrelation matrix (Table 1) reveals that most parameters exhibit 'negligible' to 'weak' correlation according to the Chaddock scale (r < 0.35). This statistical independence is crucial; it confirms that the selected twelve parameters represent distinct operational dimensions, avoiding multicollinearity and ensuring that each factor provides unique information to the final mathematical model.

One of the main problems in developing a mathematical model is the qualitative assessment of the weighting coefficients of the determined parameters. Typically, the data obtained consists of significantly different values, which significantly complicates the calculation of the mathematical model. Currently, there are several methods for calculating weighting factors: expert survey, questionnaire survey, and direct data processing.

Calculation of weight values of the specified parameters is carried out in four stages. It is required to apply mathematical statistics to solve the problem. The data for the calculation was taken from the expert assessment table. The total weight of all parameters was set to 1.0.

Stage 1. The following equation is used to calculate the sum of each parameter's degrees by the degree of change:

$$q = \sum_{i}^{n} y_i \tag{4}$$

where, y_i signifies the evaluation grade assigned to the i-th parameter, and n while represents the total count of the expert group.

Stage 2. According to the equation, the average value of the sum of scores is determined for each level of parameter variation.

$$R = \frac{1}{m}\sum q. \tag{5}$$

where, R is represents the average value of the parameter.

Stage 3. Determining the sum of the ranks of all model parameters.

$$S = \sum_{i=1}^{n} R \tag{6}$$

where, n is number of specified model parameters.

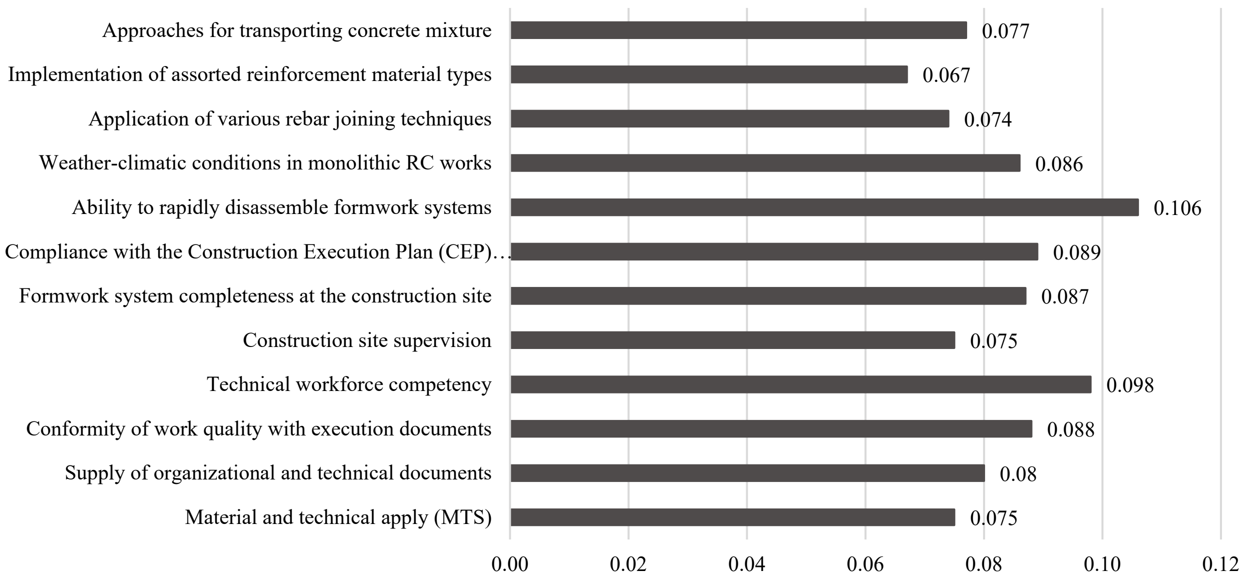

Figure 1. Diagram of weight indicators

Stage 4. Let's use the following formula to determine the weight of each parameter:

$$W_i = \frac{R}{S} \tag{7}$$

As a consequence of the calculation, we acquire the weights for each parameter (Figure 1).

According to the weighting indicators for each parameter in the table, “The possibility of quick removal of formwork” was the most essential characteristic, while “Application of various types of reinforcement products” had the least weight.

The dominance of “Ability to rapidly disassemble formwork” as the highest-weighted factor underscores the critical path nature of formwork cycles in high-rise projects. In contrast, the lower weight of 'reinforcement material types' suggests that while important for quality, it is a more standardized process with less variability in its impact on project duration compared to organizational management factors.

Therefore, a mathematical model that appropriately captures the core of the event must be applied in order to regulate the complicated indicator (CI_{optim}) for optimising the duration of monolithic reinforced concrete works and anticipating its value.

Numerous different factors that arise at the building site might have an impact on the complicated indicator (CI_{optim}). The primary idea should be considered: as the elements that the identified factors are probabilistic in nature, it is not feasible to develop an analytical model for every potential variation of the complex indicator (CI_{optim}). As a result, the complex indicator (CI_{optim}) can only be forecast with a limited level of accuracy; however, this inherent uncertainty is addressed by employing multiple averaging techniques (arithmetic, geometric, and square mean) to test the stability of the model under different weighting scenarios.

3. CALCULATION OF PARAMETER WEIGHTING FACTORS

Mathematical modelling is a tool that provides a means of studying a real object, process, or system; in this case, a mathematical model that can be studied using an electronic computing machine (ECM) in order to more conveniently conduct experimental research replaces that object, process, or system. The main stages of mathematical modelling include the following:

1. Problem formulation. The objectives of the analysis and ways to achieve the goal are determined, and an approach to solving the problem is developed.
2. Data collection and theoretical foundation study.
3. Formalisation. This stage determines the class to which the model belongs.
4. Determining the method for solving the mathematical model. The final parameters of the model are determined, taking into account the operating conditions of the studied object.
5. Model implementation. An algorithm is developed, if necessary, software is implemented and tested, and a solution to the problem is determined.
6. Data analysis. After the solution is obtained, the error generated during mathematical modelling is calculated.
7. Verification of the calculation results of the mathematical model on a real object.

The main task in experimenting is to determine the degree of influence of identified parameters on the complex indicator for optimizing (CI_{optim}) the duration of monolithic works in residential buildings.

Conducting an experiment involves executing diverse procedures on a subject to extract data regarding its specific characteristics.

The objective behind structuring an experiment is to identify the most suitable framework for capturing extensive and valid details regarding the primary research subject.

When planning an experiment, the following activities must be completed:

- to find the value of the function;
- to obtain the value of a complex indicator; and
- to determine the accuracy of the presented response function.

In addition, the experimental design allows for varying combinations of factors and assessing their impact on a complex indicator.

We will select the same function using the least squares method (LSM).

The method of least squares is a method for finding the coefficients of a linear relationship between a function of two variables, where these coefficients are determined in such a way as to give the minimum difference between the squares of value of this function.

Let us define the approximation error. The performance of the constructed model can be assessed using the approximation error. The approximation error provides a measure of the mean squared deviation between the calculated values and the actual values.

In this case, approximation error values within 5-7% indicate a successful choice of equation model. The approximation error is calculated using the following equation:

$$A = \frac{\sum [y_x - y_i] \div y_i}{n} \times 100\% \tag{8}$$

Let's calculate the Taylor inequality coefficient to assess the forecasting accuracy of the function indicator. This coefficient fluctuates between 0 and 1; the closer the coefficient value is to 0, the higher the quality of the selected model.

The Taylor inequality coefficient is calculated using the following equation:

$$K_T = \frac{\sqrt{\sum (y_i - \bar{y})^2}}{\sqrt{\sum y_i^2}} \tag{9}$$

Let us analyze the accuracy of the estimates of the equation parameters.

Let us calculate the error variance of the equation using the equation:

$$S_y^2 = \frac{\sum (y_i - y_x)^2}{n - m - 1} \tag{10}$$

Let's calculate the standard error of the equation using the equation:

$$S_y = \sqrt{S_y^2} \tag{11}$$

Let us assess the statistical significance of the equation coefficients by comparing the value computed with the following equations against the corresponding critical value.

$$t_a = a / S_a \tag{12}$$

$$t_b = b / S_b \tag{13}$$

We shall determine the coefficient of determination, which characterises the proportion of variance in the performance indicator explained by the model relative to its total variability. This coefficient is calculated to evaluate the selected equation.

Models with a value less than 50% are considered statistically insignificant, while a model is considered significant if the coefficient value is greater than 80%. Let's calculate the coefficient of determination according to Equation (14):

$$R^2 = 1 - \sum (y_i - y_x)^2 / \sum (y_i - \bar{y})^2 \tag{14}$$

Let's determine the quality of the selected equation based on statistical significance. This requires comparing the actual value with the tabulated value of the Fisher criterion.

The empirical value of Fisher's criterion is computed using the following equation as the ratio of explained variance to unexplained variance.

$$F = \frac{R^2}{1 - R^2} \times \frac{n - m - 1}{m} \tag{15}$$

These statistical criteria (Equations (8)-(15)) are not merely formal checks; they serve as a 'filter' to ensure that only the most stable and reliable organizational variables are included in the final optimization model, thereby bridging the gap between theoretical modeling and practical site application.

4. EXPERIMENTAL RESULTS AND INTERPRETATION

Similarly, let us calculate the sum of the degrees of the given values at the points with boundary conditions (0 and +1) and construct the dependence of the change in parameter values on the given expert assessments in the form of graphs (Figure 2).

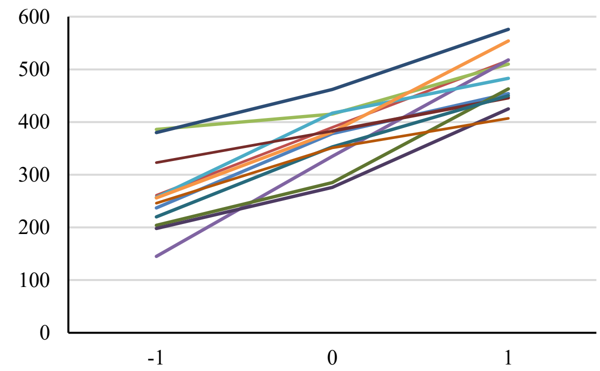

Figure 2. Dependence of changes in parameter values on the given expert assessments

Table 2 illustrates the sum of experts' evaluations gathered for every individual factor across the three designated boundary conditions (-1, 0, and +1).

Table 2. The calculated totals for the aggregate degrees of the identified parameters

No	Parameter name	-1	0	+1
1	Supply of organizational and technical documents	237.0	378.0	454.0
2	Conformity of work quality with execution documents	261.0	390.0	517.0
3	Technical workforce competency	386.0	415.0	510.0
4	Construction site supervision.	145.0	335.0	518.0
5	Formwork system completeness at the construction site	257.0	417.0	483.0
6	Compliance with the Construction Execution Plan (CEP) requirements	256.0	381.0	554.0
7	Ability to rapidly disassemble formwork systems	380.0	462.0	576.0
8	Weather-climatic conditions in monolithic RC works.	323.0	383.0	446.0
9	Application of various rebar joining techniques	204.0	285.0	463.0
10	Implementation of assorted reinforcement material types	198.0	276.0	425.0
11	Approaches for transporting concrete mixture	220.0	353.0	450.0
12	Material and technical apply (MTS)	246.0	351.0	407.0

The weighting coefficients for each parameter are calculated according to the following equation:

$$W_i = \frac{S_{(-1)} + S_0 + S_{(+1)}}{S_{total}} = \frac{237 + 378 + 454}{13342} = 0.080 \tag{16}$$

$$s_{total} = 237 + 378 + 454 + 261 + 390 + 517 + \ldots + 407 = \\ = 13342 \tag{17}$$

The parameter values are computed based on the defined weights as follows:

$$x = W_i S \tag{18}$$

where, W_i denotes the calculated weight coefficients; and S represents the calculated sum of parameter ranks depending on the variation level.

$$x_i = W_i S = 0.080 \times 237 = 18.96 \tag{19}$$

Parameter values, determined with consideration of weight-related characteristics, are summarized in Table 3. Based on Table 3, a graph of the distribution of the arithmetic average weighted value was constructed (Figure 3).

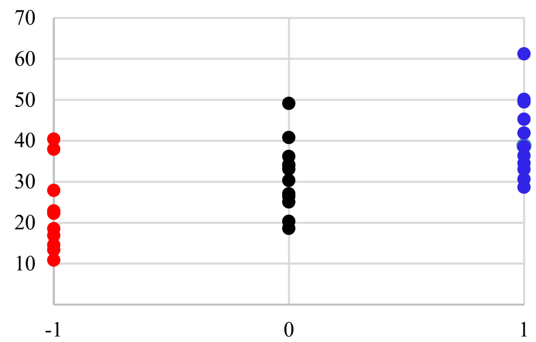

Figure 3. Distribution graph of the arithmetic average weighted value

Table 3. Parameter values are determined with consideration of weight-related characteristics

№	Parameter name	-1	0	+1	W_i	-1	0	+1
1	Supply of organizational and technical ocuments	237.0	378.0	454.0	0.080	18.89	30.286	36.376
2	Conformity of work quality with execution documents	261.0	390.0	517.0	0.088	22.849	34.142	45.260
3	Technical workforce competency.	386.0	415.0	510.0	0.098	37.929	40.778	50.113
4	Construction site supervision	145.0	335.0	518.0	0.075	10.846	25.058	38.747
5	Formwork system completeness at the construction site	257.0	417.0	483.0	0.087	22.287	36.162	41.885
6	Compliance with the Construction Execution plan (CEP) requirements	256.0	381.0	554.0	0.089	22.852	34.011	49.454
7	Ability to rapidly disassemble formwork systems	380.0	462.0	576.0	0.106	40.387	49.102	61.218
8	Weather-climatic conditions in monolithic RC works.	323.0	383.0	446.0	0.086	27.889	33.070	38.509
9	Application of various rebar joining techniques	204.0	285.0	463.0	0.071	14.556	20.336	33.037
10	Implementation of assorted reinforcement material types	198.0	276.0	425.0	0.067	13.341	18.597	28.637
11	Approaches for transporting concrete mixture.	220.0	353.0	450.0	0.077	16.869	27.066	34.504
12	Material and technical apply (MTS)	246.0	351.0	407.0	0.075	18.512	26.413	30.627

For each change value (-1, 0, +1), calculate the arithmetic average weighted value according to Equation (19) and construct the final graph based on the calculated weighted average values.

Calculation of the arithmetic average weighted value

$$M_{weightedaverage} = \frac{\sum_i^n \tilde{x}_i}{\sum_i^n W_i} \quad (20)$$

where, $\tilde{x}_i$ is the calculated parameter value at each variation level; and W_i denotes the calculated weight of each parameter.

$$M_{weighted.average} = \frac{18.989+22.849+37.929+10.846+...+18.512}{1} = \quad (21)$$
$$= 267.306$$

Let's plot the values obtained at three levels of change (-1, 0, +1) based on the calculation of the arithmetic average weighted value (Figure 4).

The dependency graph of the complex indicator is constructed by calculating the geometric weighted average value.

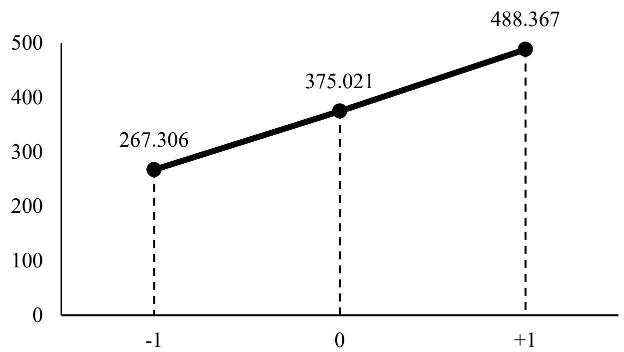

Figure 4. Weighted arithmetic average graph of the computed values

The parameter values are determined based on the specified weights using the following expression:

$$x_{geomet.weight.ave} = SW_i \quad (22)$$

where, W_i is the calculated weight of the parameters, and S represents the sum of parameter ranks depending on the variation level.

Table 4. The computed values of the weighted geometric average

No	Parameter name	-1	0	+1	W_i	-1	0	+1
1	Supply of organizational and technical documents	237.0	378.0	454.0	0.080	1.550	1.609	1.633
2	Conformity of work quality with execution documents	261.0	390.0	517.0	0.088	1.628	1.686	1.728
3	Technical workforce competency	386.0	415.0	510.0	0.098	1.795	1.808	1.845
4	Construction site supervision	145.0	335.0	518.0	0.075	1.451	1.545	1.596
5	Formwork system completeness at the construction site	257.0	417.0	483.0	0.087	1.618	1.687	1.709
6	Compliance with the Construction Execution Plan (CEP) requirements	256.0	381.0	554.0	0.089	1.641	1.700	1.758
7	Ability to rapidly disassemble formwork systems	380.0	462.0	576.0	0.106	1.880	1.920	1.965
8	Weather-climatic conditions in monolithic RC works	323.0	383.0	446.0	0.086	1.647	1.671	1.693
9	Application of various rebar joining techniques	204.0	285.0	463.0	0.071	1.462	1.497	1.550
10	Implementation of assorted reinforcement material types	198.0	276.0	425.0	0.067	1.428	1.460	1.504
11	Approaches for transporting concrete mixture	220.0	353.0	450.0	0.077	1.512	1.568	1.597
12	Material and technical apply (MTS)	246.0	351.0	407.0	0.075	1.513	1.554	1.572

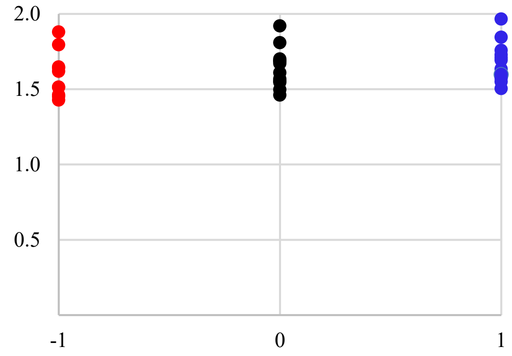

Figure 5. Distribution graph of geometric average value

For each variation value (-1, 0, +1), the weighted geometric mean was calculated using Formula 10, and the final graph (Figure 6) was constructed based on the resulting computed weighted mean values.

Calculation of the weighted geometric average

$$M_{geo.weight.ave} = \left(x_{1.geomet.weight.ave} \bullet \ldots\ldots x_{16.geomet.weight.ave}\right)^{\left(\frac{1}{\sum_{i=1}^{n} W_i}\right)} \quad (23)$$

where, $x_{1.geomet.weight.ave}$ is calculated value of parameter at each variation level; W_i is calculated values of weights.

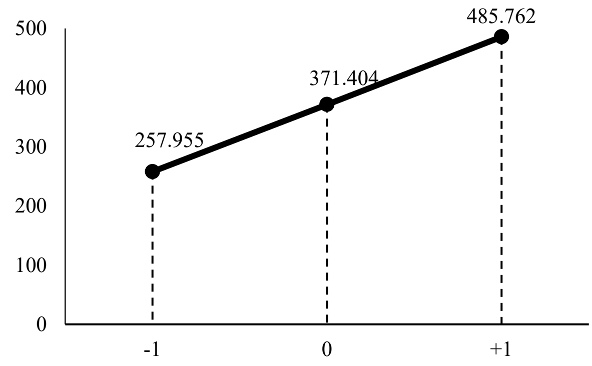

Figure 6. Weighted geometric average graph based on calculated values

Now, let's construct the dependency graph for the complex indicator by calculating the weighted average square value.

The parameter values are calculated based on the specified weights as follows:

$$x_{weight.aver.squ.} = \left(S_{i-1}^{n}\right)^2 W_i \quad (24)$$

where, W_i denotes the calculated weight of the parameters, and S represents the sum of parameter ranks depending on the variation level.

Table 5. Computed metrics of the weighted square average values

No	Parameter name	-1	0	+1	W_i	-1	0	+1
1	Supply of organizational and technical documents	237.0	378.0	454.0	0.080	4500.42	11448.28	16514.6
2	Conformity of work quality with execution documents	261.0	390.0	517.0	0.088	5963.52	13315.30	23399.3
3	Technical workforce competency	386.0	415.0	510.0	0.098	14640.51	16923.02	25557.7
4	Construction site supervision.	145.0	335.0	518.0	0.075	1572.69	8394.585	20071.1
5	Formwork system completeness at the construction site	257.0	417.0	483.0	0.087	5727.67	15079,41	20230.5
6	Compliance with the Construction Execution Plan (CEP) requirements	256.0	381.0	554.0	0.089	5850.20	12958.08	27397.4
7	Ability to rapidly disassemble formwork systems	380.0	462.0	576.0	0.106	15346.96	22685.02	35261.4
8	Weather-climatic conditions in monolithic RC works	323.0	383.0	446.0	0.086	9008.17	12665.69	17175.2
9	Application of various rebar joining techniques	204.0	285.0	463.0	0.071	2969.45	5795.698	15296.0
10	Implementation of assorted reinforcement material types	198.0	276.0	425.0	0.067	2641.61	5132.830	12170.7
11	Approaches for transporting concrete mixture	220.0	353.0	450.0	0.077	3711.07	9554.415	15526.7
12	Material and technical apply (MTS)	246.0	351.0	407.0	0.075	4553.89	9271.009	12465.2

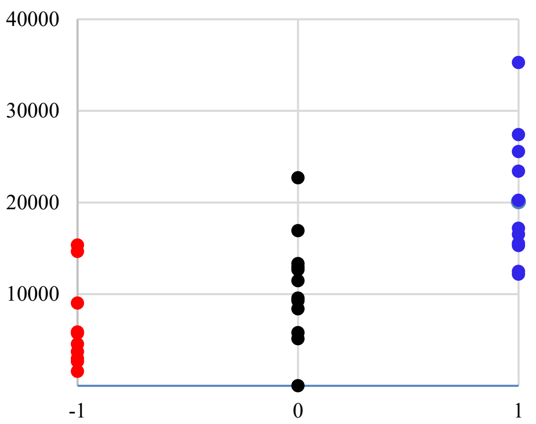

Figure 7. Distribution graph of weighted square average value

Based on Table 5, a graph of the distribution of values of the weighted square average was constructed (Figure 7).

For each variation value (-1, 0, +1), let us calculate the average weighted mean square value according to equation 12 and construct the final graph based on the computed weighted average values.

Calculation of average square mean weighted value

$$M_{aver.weight.mean.squ.value} = \left(\frac{\sum_i^n x_{weight.squa.aver.}}{\sum_i^n W_i}\right)^{\frac{1}{2}} \quad (25)$$

where, $x_{weight.squa.aver.}$ is the calculated average square mean weighted value of the parameters at each level of change; W_i denotes the calculated weight values.

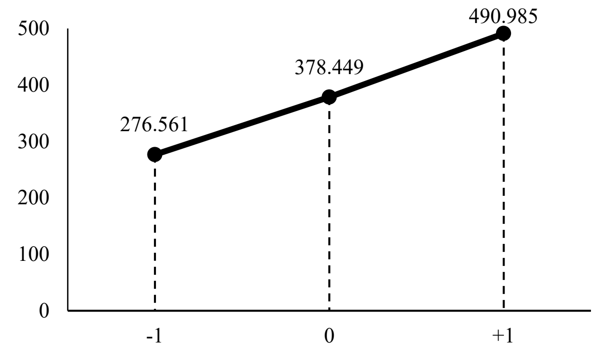

Figure 8. Average square mean weighted value graph based on calculated values

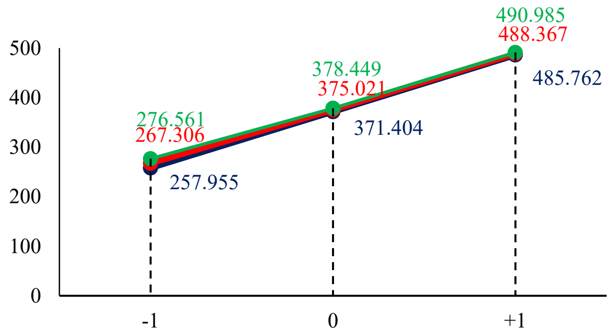

Figure 9. General graph of calculated values (arithmetic weighted average, geometric weighted average, average square mean weighted value)

The proximity of the three calculated averages (arithmetic, geometric, and square mean) in Figure 9 indicates a high degree of model stability. However, the decision to proceed with the average square mean weighted value is strategically justified. In construction duration modeling, extreme organizational delays (random failures) often have a non-linear impact; the square mean approach effectively penalizes these variances, providing a more robust safety margin for Azerbaijani high-rise projects compared to a simple arithmetic average.

As can be seen from the overall graph, the three calculated averages (arithmetic weighted average, geometric weighted average, average square mean weighted value) are quite close in their values.

To check the correctness of the function selection, we will check the obtained graphs for absolute approximation error, calculate the variance and squared deviations, and determine the Fisher criterion and the coefficient of determination.

Guided by the computational outcomes and consistent with the methodological framework established in [6], the study establishes a definitive model through the development of a linear equation to represent the weighted average square value (wherein the Taylor coefficient, representing the peak coefficient of determination, remains zero). The resulting graphic equation $y = 113.904t + 143.9$ [6] is shown in Figure 10.

The results of the equation testing show that the mathematical model is adequate and can be used as a tool for studying the complex indicator. This alignment with the results of prior specialized research [6] further validates the accuracy of the optimization model developed in this study.

Analysing the obtained graph, it can be concluded that there is a relationship between the specified parameters and the complex indicator (CI_{optim}). As the values of the specified parameters increase, the complex indicator (CI_{optim}) also increases.

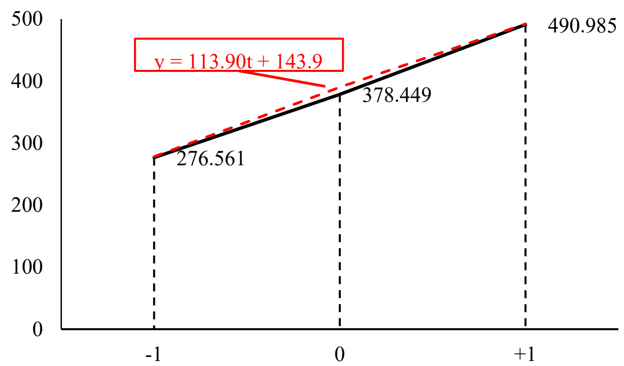

Figure 10. Graphical interpretation of the resulting mathematical model (Adapted and re-analyzed by authors based on [6])

Guided by the computational outcomes and consistent with the methodological framework established in [20], the study establishes a definitive model through the development of a linear equation to represent the weighted average square value. The resulting linear equation, $y = 113.904t + 143.9$, serves as the definitive optimization model. While the coefficients align with the foundational framework established in [20], our re-analysis confirms their validity within the specific logistical constraints of the local industry. The high coefficient of determination ($R^2 > 0.85$) and a Taylor coefficient approaching zero demonstrate that the model is not merely a theoretical construct but a reliable tool for forecasting. Practically, this implies that a single-unit improvement in collective organizational-technological state leads to a predictable 113.9-unit optimization in the complex duration indicator, allowing for data-driven scheduling in residential high-rise construction.

5. CONCLUSIONS

This study established a scientifically grounded framework for optimizing the duration of high-rise monolithic reinforced concrete works in Azerbaijan. Through the integration of expert assessments and mathematical modeling, twelve critical organizational-technological parameters were identified, with formwork turnover and site supervision emerging as the primary drivers of efficiency. The resulting linear model, validated by high statistical significance ($R^2 > 0.85$), provides a localized decision-support tool that bridges the gap between theoretical optimization and practical construction management. Unlike generalized models, this approach accounts for regional technical competencies and climatic variables, allowing engineering firms to simulate scenarios and prioritize resource allocation effectively. Ultimately, the research offers a reliable analytical basis for transforming intuitive engineering decisions into data-driven strategies, significantly enhancing the competitiveness and reliability of the local building sector. The integration of mathematical precision with Azerbaijan's specific construction normative database ensures that this model serves as a pioneering strategic tool for improving the efficiency of large-scale infrastructure projects.

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