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RESEARCH ARTICLE

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A MATHEMATICAL MODEL FOR MEASURING THE CONSTRUCTION QUALITY OF GOVERNMENT PROJECTS USING NONLINEAR REGRESSION TECHNIQUE

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ABSTRACT

Presents the results of a research study carried out to examine the main factors that affect the quality of a construction project. The aim is to identify the factors that appear to be closely related to the construction quality of government projects. The ultimate goal is to provide clients, projects, managers, designers, and contractors with information that can help them work more efficiently with their limited resources and thereby achieve better quality results. 50 recently completed government construction projects in Iraq were examined and analysed. The results of the survey showed that the factors that most influenced the quality of the construction according to the materiality index were: the cost indicated by the contractor to complete the work, the specialization and accumulated experience of the contractor in the field of work. Financial efficiency of the contractor, delay in the contractor's lending, work interruption, experience of the team leader in supervision and quality control, time saved by the contractor for completing the work, delay of the employer in issuing change orders, availability of infrastructure, easy access to the workplace and quality the materials used in the work.

Key words: construction, quality, management, Iraq, experience, change orders.

INTRODUCTION

Quality systems and quality are topics that are receiving increasing attention worldwide [1]. The end product must be manufactured to the required standard in any industry that provides customer satisfaction and value for money. The quality requirement of the end product is no less in the construction industry than in any other industry. The high construction costs make it necessary to guarantee the quality of the end product. Quality is defined in BS 4778 Part 1: Quality Vocabulary (British Standards Institution and ISO 9001: Quality Systems: A Model for Quality Assurance in Design, Development, Production, Installation and Service [2] as the sum of the characteristics and characteristics of a product / service that affect its ability to meet certain needs / impacts with particular reference to the construction industry, quality is defined as:

•fitness for purpose [3]

•the effective achievement of agreed goals between the client and the main contractor [4]; or.

•the conformance to requirements of clients as defined by [5].

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This article presents the results of a research study conducted to identify the main factors influencing the quality of government construction projects in Iraq. A total of 50 recently completed construction projects were examined and analyzed. With the help of the materiality index and nonlinear regression analysis, the factors influencing the quality of the construction project were determined.

FACTORS THAT AFFECT THE QUALITY OF THE PROJECT

Different researchers have made different attempts to define the success factors of the criticality design [6], [7], [8] and [9]. The literature is rich in lists of variables. It is supposed to affect the quality of the construction project. There are some common variations in more than one list, but there is certainly usually no agreement on the variables. A review of this earlier research reveals some common variable issues that affect the quality of construction projects. The perceived factors that influence service quality can be roughly divided into the headings customer, project, project environment, project team leader, project procedure and project management procedure.

A. *Research Aims*

The aim of this research is:

Investigate the main causes of poor construction quality in Iraqi government projects.

Developing a model to enable the concerned government agencies to predict the expected quality of government construction projects upon awarding the contract.

B. *Research Justification*

Several studies have been carried out to examine the real factors that affect the quality output of government building projects either at the design stage or during construction. No attempts were found to investigate how the information available at the time of the award of the contract was used to predict the expected quality of construction projects.

C. *Research Methodology*

A wide range of literature is reviewed to find the most common and influential causes of quality in construction projects. The questionnaire form is then distributed to owners, consultants, supervisory engineers and contractors in the public and private sectors. Expert opinions were analysed to identify ten factors influencing the construction quality of government projects. Data on these ten criteria were obtained from completed project records and then used to develop the nonlinear regression measurement model.

D. *The questionnaire results*

The sixty-five factors that affect quality have been divided into fourteen main groups. In terms of owner, design, specifications, project, contract, contractor, monitoring and implementation team, subcontractor, management, financial aspects, materials and equipment, implementation method, systems used, and labour and external factors These groups were included in a sample questionnaire in order to obtain opinions from local experts on their applicability to the case study. Appendix (A) shows the questionnaire form used with (65) factors that influence construction quality and project completion. Sort and sort based on the questionnaire results discussed later. A total of (90) (110) distributed questionnaires were collected, which corresponds to a response rate (82%). Ten of the factors that most affect quality are: the cost provided by the contractor to complete the work, the specialization and accumulated experience of the contractor in the field of the work. Financial efficiency of the contractor, delay in the contractor's lending, work stoppages, experience of the team leader in terms of supervision and quality control, time the contractor allows to complete the work, delay in issuing change orders by the employer, availability of infrastructure, easier Access to the workplace and quality of the materials used for the work.

E. *Verification of the Questionnaire Results*

The reliability and validity of the questionnaire results are checked using the Cronbach alpha technique using equation (1), with the normal range of the Cronbach coefficient value (alpha) being between (0.0) and (1.0). The closer the alpha is to (1), the greater the internal consistency of the data. [10].

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_i Si^2}{St^2}\right) \quad \dots (1)$$

Where:

K: number of items in a group.

Si 2: the variance associated with the item (i).

St2: the variance associated with the sum of all (k) item scores.

Table (1) shows the reliability and validity values according to Cronbach's alpha for each group in the questionnaire. Cronbach's alpha values were found to be in the range of (0.906 to 0.981). This range is considered high, so the reliability and validity of each group in the questionnaire is ensured, since validity is measured according to equation (2) [10].

$$V= \sqrt[2]{\alpha} \quad \dots (2)$$

TABLE 1: RELIABILITY AND VALIDITY OF GROUPS FACTORS

Group of factors	No. of Factors	Reliability	Validity
Owner related factors	8	0.931	0.964
Design and specification related factors	6	0.91	0.953
Project related factors	7	0.932	0.965
Contract-related factors	3	0.951	0.975
Factors related to the contractor	5	0.966	0.983
Factors related to the supervision and implementation team	4	0.921	0.96
Factors related to the subcontractor	3	0.931	0.965
Management related factors (employer, consultant and contractor)	5	0.95	0.975
Factors related to financial issues	5	0.981	0.99
Factors related to materials and equipment	5	0.96	0.979
Factors related to the method of implementation	4	0.906	0.952
Factors related to the systems used	4	0.993	0.996
Factors related to the workforce	3	0.929	0.964
External factors	4	0.934	0.966
Total Factors Affect Group	65	0.914	0.95

F. (Cronbach's Alpha)

Furthermore, the relative importance of influencing factors is calculated according to [11], which used the relative importance index (RII) for this purpose. The five-point Likert scale was adopted from (1 = weak influence) to (5 = very high influence) and converted into indicators of relative importance (RII) using equation (3) for each factor in the questionnaire.

$$\text{RII} = \frac{5*n5+4*n4+3*n3+2*n2+1*n1}{5*(n1+n2+n3+n4+n5)} * 100 \quad ..(3)$$

Where:

nl, n2, n3, n4, and n5 (the number of respondents who selected):

nl: Number of respondents who had little effect.

n2: Number of respondents having chosen some effect.

n3: Number of respondents picking the average effect.

n4: Number of High Effect respondents.

n5: number of respondents who selected very high effect.

In contrast, these five expressions are defined by equal intervals, as the following:

10.0 ≤ little effect (LE) ≤ 20.0

20.0 ≤ some effect (SE) ≤ 40.0

40.0 ≤ average effect (AE) ≤60.0

60.0 ≥high effect (HE) ≤80.0

80.0 ≤ very high effect (VHE) ≤ 100

The RII values were found to be in the range (0.217-0.795) as mentioned in Appendix (A). Taking into account all factors with a relative importance greater than (65%), the number of most important factors (10 factors) became (10) that were used in developing the NLR prediction model. The ten selected factors are listed in Table (2).

G. Data Acquisition

The data needed to develop nonlinear regression models come from (50) school projects, all of which were completed in the period (2012-2020). The information comes from the records of the General Directorate of School Buildings in Education. The projects included in this study were selected for having the same layout, number of floors, floor space, and acquisition method. Once sufficient information has been identified, the construction quality prediction is done using non-linear regression.

Table 2: The most important factors affecting the quality of government projects

No	**factors affecting**	**RII%**	**Rank**
1.	The cost provided by the contractor to complete the work	87.8	1
2.	Specialization and cumulative experience of the contractor in the field of work	85.6	2
3.	Financial Efficiency of Contractor (Provide Cash Flow)	84.2	3
4.	Late payments due to the contractor	78.9	4
5.	stop working	77.6	5
6.	The experience of the team leader in supervision and quality control	72.9	6
7.	The period provided by the contractor to complete the work	72.2	7
8.	Delayed issuance of change orders	72	8
9.	Ease of access to the site and availability of infrastructure on the site	70	9
10.	The use of high-quality materials at work.	65.8	10

The data are in groups (training, test and verification) and assignment (75%) of the data to the training group, (20%) to the verification group and (5%) to the test group for the performance model. (100) verification measures, (10) verification and (2) tests of this used model.

The main variables that influence construction costs in the results of the questionnaire have been modified to relate the loss of analysis as follows:

F1: The cost provided by the contractor to complete the work.

F2: Specialization and cumulative experience of the contractor in the field of work

F3: Financial Efficiency of Contractor (Provide Cash Flow)

F4: Late payments due to the contractor

F5: stop working duration. I6: the experience of the supervising engineers.

F6: The experience of the team leader in supervision and quality control

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F7: The period provided by the contractor to complete the work

F8: Delayed issuance of change orders

F9: Ease of access to the site and availability of infrastructure on the site

F10: The use of high-quality materials at work.

H. Nonlinear Regression Models

The Levenberg-Marquardt technique is used to develop the NLR equations. This technique relies on inserting variables into a nonlinear equation that is constructed according to some values of the parameters of the equation and is examined by the coefficient of determination test. The best values of the coefficients of the equation are obtained through a series of iterations. The equation is then examined by comparing the check values with the actual values. Table (3) shows the best values of the coefficients of the equation obtained.

Table 3: Parameters estimates for model (QUALITY)

Parameter	Estimate	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
β_1	0.05067	0.1793178	-0.33154	0.43287
β_2	3.89517	937886.2537639	-1999053.33420	1999061.12454
β_3	0.17333	50539.7905414	-107722.840	107723.187
β_4	-2.557E-12	6.128E-10	-1.309E-09	1.304E-09
β_5	13.370	123.3408862	-249.52452	276.26523
β_6	0.1376	0.0302089	0.07318	0.20196
β_7	0.0224	0.0085749	0.00414	0.04070
β_8	-0.1354	41304.4922202	-88038.57661	88038.30573
β_9	-7.7962	2695.1585059	-5752.39058	5736.79816
β_{10}	-0.0175	6.2957679	-13.43658	13.40165
β_{11}	0.0002	0.0138734	-0.02933	0.02981
β_{12}	1.2594	12.3362839	-25.03474	27.55360
β_{13}	1.6517	926846.7649070	-1975525.46413	1975528.76760
β_{14}	-0.3152	176632.7896516	-376484.19446	376483.56400
β_{15}	-0.0254	0.4765990	-1.04123	0.99046

According to the aforementioned procedure, the following final delivery time estimation equations were developed using (NLR) for models (QUALITY):

(QUALITY)=0.05067*(F1)+3.89517*(F2)0.17333+(-2.557E-12)*(F3)13.370+(F4)0.1376+0.0224*(F5)+(-0.1354)*(F6)+(-7.7962)*(F7)-0.0175+0.0002*(F8) 1.2594+1.6517*(F9)-0.3152+(-0.0254)*(F10) .... (4)

I. Models Accuracy and Validity

One of the most important steps in developing a model is to test its accuracy and validity. It includes testing and evaluation of the developed model with some test or validation data. The validation data should be some representative data from the target population but was not used in developing the model. The expected final delivery time for the projects is projected using Equation (4) for the model. The results are shown in Table (4). It is now evident that the model performs well from the residual values shown in the table.

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Table 4: Comparison of observed and predicted data of model

Case Project No.	Observed ((QUALITY))	Predicted ((QUALITY))	Residual value
33	0.80500	0.75840	-0.04660
34	0.80000	0.79748	-0.00252
35	0.75900	0.75170	-0.00730
36	0.66700	0.70761	0.04061
37	0.60700	0.63801	0.03101
38	0.79500	0.75635	-0.03865
39	0.77500	0.77878	0.00378
40	0.73200	0.72933	-0.00267

The coefficient of determination is used to assess the validity of the formulas derived from the NLR model of construction quality (quality) for public school construction projects. The natural logarithm (Ln) of the expected (quality) values is plotted against the natural logarithm (Ln) of the observed (actual) values from the validation data set, as shown in Figure (1).

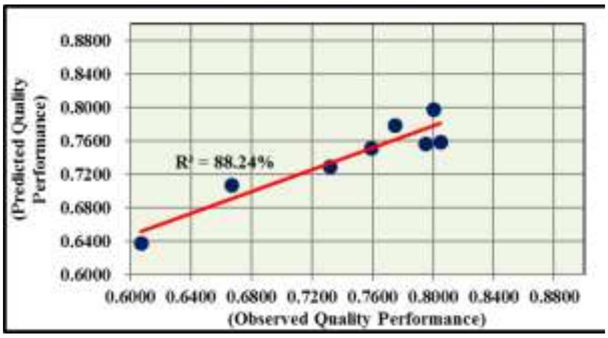

Figure 1: Observed vs. Predicted (QUALITY) using model (Quality)

From these figures it can be seen that the NLR model can possibly be generalized to work with this type of data. I found that the coefficient of determination (R2) for the model is (88.24%). From this it can be concluded that this model shows a very good agreement with the actual observations.

J. Models Evaluation

Statistical measures that can be used to measure the performance of prediction models include the following:

i. Mean Percentage Error (MPE):

$$\mathbf{MPE} = \left(\sum \frac{\mathbf{A}-\mathbf{E}}{\mathbf{A}} / \mathbf{n}\right) * \mathbf{100\%} \qquad \dots(5)$$

Where:

A: actual value

E: estimated value or predicted value

n: total number of cases (8 for validation).

ii. Root Mean Squared Error (RMSE):

$$\mathbf{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\mathbf{E}-\mathbf{A})2}{\mathbf{n}}} \qquad \dots(6)$$

iii. Mean Absolute Percentage Error (MAPE):

$$\mathbf{MAPE} = \frac{\sum \frac{|A-B|}{A} * \mathbf{100\%}}{n} \qquad \dots\dots(7)$$

iv. Average Accuracy Percentage (AA%):

AA% = 100 % -MAPE .... (8)

v. The Coefficient of Determination (R2).

vi. The Coefficient of Correlation (R).

MAPE and percent RMSE are used as a measure of mean error only in independent test data. The results of these statistical parameters of the model are shown in Table No. (7), where it was found that the average percentage precision and the average precision obtained from the NLR model are (2.9990%) and (0.0314).

Table 5: Performance testing results of the NLR model (Quality)

Description	Statistical Parameters
MPE	-0.2277%
RMSE	0.0314
MAPE	2.9990%
AA	97.001%
R	0.939
R^2	0.882

K. *CONCLUSIONS*

As a result of this research, ten factors are believed to have the greatest influence on construction quality. This is based on expert opinions collected through a questionnaire form sent to owners, consultants, supervising engineers and contractors for school construction projects in Iraq. These reasons are: the cost of completing the work provided by the contractor, the contractor's accumulated expertise and experience in the field of work, the financial efficiency of the contractor (provision of cash flow), late payments to the contractor, termination of site, the Team Leader's experience in supervision and quality control, the time provided by the contractor to complete the work.

Delayed issuance of change orders, easy access to website and availability the infrastructure on the site, the use of quality materials in the work.

Based on these ten factors, all created in the period (2012-2020), a model was developed using nonlinear regression to predict the construction quality of public school construction projects before work began. Statistical validation metrics (MPE, RMSE, MAPE, AA and R2) were used to validate and generalize the model. The models developed have shown excellent performance that can be generalized in Iraq

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Appendix (A)

No	Factors affecting the quality of government buildings
Group (1): Owner -related factors	
1	The type of owner and how important it is
2	How good the project is required for the owner
3	Delayed issuance of change orders
4	Owner's experience with similar projects

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5	Owner's experience with similar projects
6	Reducing the project implementation period
7	Reducing the project budget
8	stop working
Group (2): Design and specifications -related factors	
9	Sufficient prequalification meetings with the designer
10	Similar work and previous design experience
11	The level of commitment to the principle of improving and developing quality in design with continuity of work
12	Delay in delivery of design documents
13	Complexity in project design
14	Use of locally available materials and methods of implementation
Group (3): The project-related factors	
15	The type and nature of the project
16	Estimated duration of the project
17	Estimated project implementation cost
18	Existence of warehouses to store and collect the necessary materials for work
19	The overall site is well organized
20	The breadth of the site and ease of movement of workers and equipment
Group (4): Contract -related factors	
21	Type of Contract
22	Clarity of the terms of the contract greatly
23	Provide detailed items for specifications, quantities and drawings.
Group (5): Contractor -related factors	
24	The time period provided by the contractor to complete the work
25	Specialization and cumulative experience of the contractor in the field of work
26	Splitting the contract for more than one secondary contractor
27	The cost provided by the contractor to complete the work
2	A successful previous working relationship between the project parties (the contractor completed the work

8	on time, budget and required quality)
Group (6): Team supervision and implementation -related factors	
29	Engineering awareness of the importance of controlling work quality to supervise and implement engineers
30	The experience of the team leader in supervision and quality control
31	The experience of the contractor team leader in doing work within the required engineering specifications
32	Cooperation between supervision and implementation teams
Group (7): Sub-contractor -related factors	
33	Owner's contribution to selecting the sub-contractor
34	Existence of a work contract on good and fair terms between the general contractor and the sub-contractor
35	Specialization, technical competence and expertise of the sub-contractor
Group (8): Management -related factors	
36	The importance of the documentation system for all parties involved in the contracting and implementation process (correspondence, reports, change orders, schedules, workshop drawings, tests)
37	Forming committees to monitor the work quality and accrediting the laboratories that are eligible for examination
38	Establishing a comprehensive quality system at the project level
39	The appropriate organizational and administrative structure for the employer and contractor to follow up the quality system
40	The project parties are concerned with cost and time more than the quality of the project
Group (9): Financial issues -related factors	
41	Financial Efficiency of Contractor (Provide Cash Flow)
42	Credit the contractor with the full amount of work performed
43	Late payments due to the contractor
44	Comply with the instructions for the procedures of credit

45	Agreeing on the form of financial deductions for works that are totally or partially rejected
	Group (10): Materials and equipment-related factors
46	The use of high-quality materials at work
47	Prepare lists of materials that will be imported or manufactured in advance
48	Equipment price fluctuations
49	Material price fluctuations
50	Abundance and efficiency of equipment and machines used in work
	Group (11): Execution method -related factors
51	Preparing and using executive plans
52	The use of a comprehensive and continuous supervision system
53	Clear steps to receive the completed work
54	Examining the final stages of the completed works
	Group (12): The Systems Used -related factors
55	Application monitoring systems and quality control
56	Application and use of schedules
57	Using a cost control system
58	Implementation of the prevention and safety program
	Group (13): Workforce -related factors
59	Use a team with specialization or work experience
60	Providing periodic awareness programs in the field of quality to raise the level of workforce efficiency
61	Adopting the principle of material and moral incentives for workers
	Group (14): The external environment-related factors
62	The stability of the security situation
63	Impact of environmental restrictions
64	Impact of social restrictions
65	Impact of legal restrictions