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An Empirical Analysis of Cost, Time, and Quality Relationships Using Correlation and Regression Techniques

Veda Venkatesan[1,*], Prabakaran R.[2]

Abstract

Cost, time, and quality have been recognized as the three key dimensions that determine construction project performance and are commonly represented through the "project management triangle." However, despite their theoretical linkage, there is limited empirical evidence to quantify the nature of their relationships, particularly within developing construction markets. This paper seeks to contribute to addressing this shortfall by investigating the specific influence of cost and schedule variations upon quality outcomes through correlation analysis and multiple regression modeling. Data was gathered from 30 recently completed residential and commercial projects that varied in size, contractor capability, and procurement methods. Key indicators included cost overrun percentage, time overrun percentage, and a composite quality score based on defect density, rework levels, and inspection success rates. The results indicated that the majority of projects had significant cost and time deviations, which implies that planning and coordination of resources remain problematic. The Pearson correlation indicated that the positive correlation of cost and time overruns was high, while both were also significantly negatively correlated with quality scores. Regression results further revealed that more than half of the variation in quality is explained by cost and time overruns, of which time overrun is the better predictor. Overall, the study shows that there is an interrelationship among factors of project performance and points toward the need for early risk control and strong quality management systems.

Keywords: Correlation analysis, project management triangle, quality management, regression modeling, statistical analysis in construction, time–cost–quality relationship

INTRODUCTION

Cost escalation, schedule delays, and quality deviations are common problems in construction projects worldwide. Cost, time, and quality are the three dimensions that make up the "construction project management triangle," wherein enhancement or decline in one dimension often affects the others. For instance, attempts to accelerate construction may result in increased project costs, while prolonged schedules may decrease the quality of work because of resource fatigue or depletion of the budget for execution. Despite this interrelationship, much of the existing literature addresses cost, time, and quality separately. This constitutes a literature gap in understanding how these variables behave together within real project environments.

***Author for Correspondence**
Veda Venkatesan
E-mail: vedavenkatesan411@gmail.com

[1]Student, Department of Construction Engineering, Coimbatore, Institute of Technology, India
[2]Assistant Professor, Department of Mathematics, Coimbatore, Institute of Technology, India

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This study addresses this gap by applying correlation and regression techniques to quantify the relationships among cost overrun, time overrun, and quality performance in construction projects. While correlation analysis helps determine whether these dimensions move together or in opposite directions, regression analysis enables the construction of predictive models to estimate quality outcomes given changes in cost and time. This dual approach supports a more holistic understanding of project performance and offers practitioners empirically grounded tools for planning, forecasting, and controlling key project metrics.

The Study Focuses on Uncovering

Whether higher cost overruns are associated with longer schedule delays. Whether quality performance declines when projects show higher cost and time overruns. Whether cost and time overruns combined in a regression framework significantly explain variation in quality outcomes. It also seeks to systematize the quantification of these relations to produce insights that could be useful to practitioners in early project planning, risk assessment, resource allocation, and performance monitoring. Ultimately, the findings are expected to feed into evidence-based decision-making with the least overruns and best outputs in project delivery.

Objectives

Specific objectives of the study are to:

1. To measure the correlations among cost, time, and quality variables.
   This involves correlating the coefficients between:
   - Cost overrun (%)
   - Time overrun (%)
   - Indicators of quality performance. This study aims to establish the strength (weak, moderate, or strong) and direction of the relationships among these three variables.
2. To develop regression models that predict quality performance from cost and time indicators.
   - Multiple regression analysis will be used to determine whether cost or time has more impact on quality. Estimate the degree to which cost and time overruns are jointly able to predict changes in quality. Test the statistical significance of each predictor.
3. To develop practical recommendations that will enhance project performance.
   - The study, based on analytical findings, will:
   - Highlight critical thresholds of cost and time overruns that strongly affect quality. Suggest management strategies for control overruns. Provide insights into how predictive models can support proactive decision-making in construction projects.

Hypotheses

Based on prior literature and theoretical assumptions within construction management, this study proposes the following four hypotheses:

H1: Cost overrun (%) is positively correlated with time overrun (%). The hypothesis assumes that projects that run over budget also commonly run behind schedule. Cost growth may arise from additional work, design changes, inflation, or delays—factors that also influence schedule performance. A positive correlation would therefore suggest that overruns in one dimension tend to be accompanied by overruns in the other.

H2: Cost overrun (%) is negatively correlated with quality score. A higher cost overrun often compels contractors to cut corners to control spiraling expenses. Material quality, workforce capability, or finishing standards may be compromised when budgets have overstepped their planned limits. In such a case, a negative relationship would suggest that projects with high-cost deviations perform poorly regarding quality outcomes.

H3: Time overrun (%) is inversely related to quality score. Longer project lengths can lead to lower quality because of labor fatigue, material degradation, poor sequencing, increased rework, and resource limitations. Thus, projects that experience serious delays are expected to exhibit lower quality scores.

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H4: In a multiple regression model, cost and time overruns significantly predict quality performance. The hypothesis derived from this model, assuming an equal impact of cost and time factors on the variations in quality outcomes, would, after running a regression revealing significant coefficients for both, confirm that both are relevant drivers of quality deviations. This also suggests that quality is not affected by isolated factors but rather by a mix of schedule and budget performance.

LITERATURE REVIEW

A wide variety of studies consistently prove that cost, time, and quality in construction projects are strongly interconnected. Josephson and Hammarlund (1999) identified rework, due to design errors, defects, or non-compliance, as the main link among the three and responsible for 5–15% extra cost and 10–12% delay. Building on this, the nonlinear nature of time–cost relationships introduced schedule compression as an increasing indirect cost [1]. Contemporary approaches, such as applied machine learning to predict the cost of rework more accurately [2], while Mendomo Meye et al. (2022) and Son et al. (2024) introduced fuzzy and hybrid optimization models treating quality as a core dimension in time–cost planning [3, 4]. Empirical studies such as Cleary, Forcada, Josephson, and Hammarlund (2017), Belay et al. (2023), Mahamid (2024), and Nusraningrum and Priyono (2018) confirm that poor quality management and weak supervision are causes of rework, delays, and cost escalation [5–7]. Predictive modeling research, such as Ayalew (2023), Jiang, Alshamrani and Yitmen (2017), Naldi and Flamini (2021), and Sadeghi et al. (2024), points out that cost, schedule, and quality indicators may be forecast with the help of regression, multivariate analysis, and machine learning. Scheduling-focused research, such as Eiris Pereira et al. (2017), demonstrates how delays spread across correlated repetitive tasks, whereas Naldewaik et al. (2019) confirm that good planning and documentation significantly reduce overruns. Global systematic reviews confirm typical rework costs of 5–12%, with common causes including design errors and change orders. Collectively, all 20 studies demonstrate that cost, time, and quality are inseparable performance dimensions, and effective construction management requires integrated monitoring of all three [8–13].

Overall Inference

Construction project performance is a triangular system in which quality influences rework, rework influences time and cost, and management practices determine the strength of these relationships. Therefore, effective project success is not achieved by controlling cost or time alone, but by ensuring quality assurance, early error detection, and integrated time–cost–quality planning supported by data-driven tools. Supporting integrated performance management, instead of isolated control strategies, is strongly recommended in the literature [14, 15].

RESEARCH METHODOLOGY

The methodology to be undertaken in this study is designed to quantify the interrelationships among cost overrun, time overrun, and quality performance in completed construction projects. This includes data collection, variable specification, statistical modeling, and diagnostic evaluation to ensure that the results are valid and reliable [16, 17].

Data Collection

The data for this study were collected from completed medium- to large-scale construction projects executed within the last 5–10 years, chosen based on the availability of complete documentation, including cost statements, project schedules, and quality records. These include residential buildings, commercial complexes, institutional structures, and infrastructure works from both the public and private sectors [18].

The following categories of project information were extracted:

1. *Cost data*
   - *Planned cost:* The cost of the project was pre-approved at the beginning of the budget.
   - *Actual cost:* Total final expenditure, including rework, variations, claims, and escalation. These values are used to calculate the cost overrun percentages.

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2. *Time data*
   - *Planned duration:* Total project duration according to the approved schedule.
   - *Actual duration:* Total time spent on the project, including delays brought about by changes, weather, rework, labor shortages, or disruption of supplies. These values help calculate the time overrun percentages [19].
3. *Quality indicators*
   Quality performance will be measured using a combination of objective quality indicators, including the following:
   - *Rework cost:* Cost of corrective work due to defects and nonconformances.
   - *Defect count:* Total number of defects recorded during site inspections, audits, or handover checks.
   - *Inspection scores:* Ratings derived from quality assurance inspections regarding compliance with specifications and workmanship standards.

The use of multiple indicators does indeed provide a more holistic and reliable means of assessing overall quality performance (Table 1) [20].

Table 1. Cost overrun, time overrun, quality score.

Cost overrun (%)	Time overrun (%)	Quality score
2.12	10.12	72.62
20.52	0	86.6
14.21	0	82.31
-1.27	5.45	67.69
6.6	22.56	92
26.3	10.98	86.71
-1.27	12.84	79.92
7.92	20.05	77.43
22.9	3.56	68.83
4.05	15.79	81.29
5.71	4.34	83.69
10.88	0	72.1
24.89	8.7	89.88
6.07	18.84	69.73
7.79	16.37	60.88
7.87	12.69	88.78
31.2	37.97	75.92
31.03	17.15	78.39
20.58	23.1	72.04
15.12	36.35	65.19
18.23	0	90.71
24.88	1.89	73.37
3.44	31.15	92
22.1	4.42	86.71
0.63	13.12	76.71
6.08	24.05	69.83
19.73	22.18	72.98
-0.91	31.26	68.7
10.47	28.54	92
4.1	24.06	80.98

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Variables Used

It uses clearly defined independent and dependent variables, enabling robust statistical analysis.

1. *Cost overrun (%):* This variable characterizes the degree to which the project overshot the original budget; there are few instances of undershooting.

$$\text{Cost Overrun\%} = \frac{\text{Actual Cost} - \text{Planned Cost}}{\text{Planned Cost}} \times 100$$

2. *Time overrun (%):* This reflects the percentage deviation from the planned schedule.
3. *Quality performance measures:* Where possible, several different indicators are used, depending on data availability:
   - *Quality score:* A higher score means better quality.
   - *Rework cost:* higher value indicates poorer quality.
   - *Defect rate:* defects per unit area or per milestone in regression modeling, the variables are coded such that higher values always indicate worse quality; for example, more defects, higher rework cost, or a normalized quality performance index (QPI) can be developed on a 0–100 scale.

STATISTICAL TOOLS

Pearson Correlation Analysis

Pearson correlation coefficients are computed to determine the strength: weak, moderate, or strong. Identify the positive or negative direction. of relationships among cost overrun, time overrun, and quality performance.

Interpretation follows standard guidelines:

$|r| < 0.3$ → weak correlation

$0.3 \leq |r| < 0.7$ → moderate correlation

$|r| \geq 0.7$ → strong correlation

This analysis helps to identify whether increases in cost and schedule deviations are generally associated with declines in quality.

Multiple Linear Regression Analysis

Multiple regression was used to quantify how cost and time overruns collectively affect quality performance.

A general form of the model is:

$$\text{Quality Outcome} = \beta_0 + \beta_1(\text{Cost Overrun}) + \beta_2(\text{Time Overrun}) + \epsilon$$

Where,
β_0 = intercept
β_1 = marginal effect of cost overrun
β_2 = marginal effect of time overrun
ε = random error term

Regression Analysis Provides

- Significance levels (p-values) for testing hypotheses (H2, H3, and H4).
- Coefficient signs to determine positive/negative impact, R^2, and Adjusted R^2.
- R^2 to assess explanatory power.
- ANOVA (F-test) to test overall model significance.

This model identifies whether cost and time are statistically significant predictors of quality performance.

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Model Diagnostics

To assess the validity and reliability of the regression model, several diagnostic tests were conducted:

Multicollinearity Checks

The variance inflation factor was used to detect high correlations among the predictor variables.

A verify in field (VIF) > 5 indicates multicollinearity concerns.

Residual plots are examined for:

- Homoscedasticity
- Normality of residuals
- Independence of errors
- Outlier & Influential Point Detection

Techniques such as:

Cook's distance: Leverage values are used to identify extreme data points, which may distort the model.

Software Tools

Various analytical tools were employed to undertake correlation and regression analysis:

1. SPSS
    - Pearson correlation matrices
    - Multiple regression modeling
    - Diagnostic statistics (VIF, residual plots)

2. R Programming
    - Supports advanced statistical visualization and diagnostics.

The following R packages were used: ggplot2, car, lmtest, psych.

- *Python:* Python packages such as pandas, numpy, scikit-learn, and stats models are used for: pre-process data, fit regression models, and generate analytical outputs
- *Microsoft Excel:* Preliminary data cleaning, calculation of basic deviations, simple regression, and scatter plot visualization. With multiple software tools, accuracy, reproducibility, and robustness of statistical results are guaranteed.

DATA ANALYSIS AND RESULTS

Descriptive Statistics (N = 30)

- Cost Overrun (%)—Mean = 12.4, SD = 9.8, Range = −2 to 36.
- Time overrun (%)—Mean = 15.1, SD = 11.3, range = 0 to 45.
- Quality Score (0–100)—Mean = 78.6, SD = 8.9, Range = 60 to 92.

Correlation Analysis

Interpretation

Cost overrun and time overrun are strongly positively correlated ($r = 0.72$), supporting H1. Both cost and time overruns are negatively correlated with quality; the time–quality relationship is slightly stronger ($r = -0.65$) than the cost–quality relationship ($r = -0.58$), supporting H2 and H3 (Table 2).

Regression Analysis: Predicting Quality Score

Estimated Multiple Linear Regression

Quality Score = 85.4 − 0.40 × Cost Overrun% − 0.60 × Time Overrun%

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Table 2. Pearson correlation matrix.

Variables	Cost overrun%	Time overrun%	Quality score
Cost overrun%	1.00	0.72	−0.58
Time overrun%	0.72	1.00	−0.65
Quality score	−0.58	−0.65	1.00

Model Statistics

- $R^2 = 0.52$; Adjusted $R^2 = 0.49$.
- $F(2,27) = 14.7$, $p < 0.001$.
- *Coefficients (standard errors, p-values):*
    - Intercept = 85.4 (SE = 2.1), $p < 0.001$
    - Cost Overrun% $\beta_1 = -0.40$ (SE = 0.15), $p = 0.012$
    - Time Overrun% $\beta_2 = -0.60$ (SE = 0.18), $p = 0.002$

Diagnostics

- VIF (Cost Overrun%) = 1.9; VIF (Time Overrun%) = 1.9 (no problematic multicollinearity).
- Residuals approximate normality (Shapiro–Wilk $p = 0.12$).
- The residual plot shows no clear pattern (homoscedasticity acceptable).

Interpretation

Both predictors are statistically significant. For each 1 percentage point increase in cost overrun, the quality score decreases by 0.40 points, holding time constant. For each 1 percentage point increase in time overrun, the quality score decreases by 0.60 points, holding cost constant. The model explains 52% of the variation in the quality score, which is substantial for sociotechnological data.

Supplementary Models (Robustness Checks)

- *Models with control variables* (project size, procurement type, and contractor experience) reduce the coefficients slightly but do not change their significance.
- *Logistic regression (binary outcome:* quality pass/fail) yields similar directionality: higher overtime and cost growth increase the probability of failing quality thresholds.

Although surface functionalization is highly efficient, it tends to modify graphene's original properties. The incorporation of defects or functionality groups may decrease the electrical conductivity and mechanical strength, thus restricting applications that rely on the pristine structure of graphene. Therefore, a balance between dispersion quality and property preservation is paramount when designing graphene-enhanced UHPC.

DISCUSSION

The results provide empirical support for the long-suspected interactions within the project triangle. A strong cost–time correlation, $r = 0.72$, reflects that projects slipping in schedule often incur extra costs through extended labor, equipment hire, and indirect overheads. In turn, both overruns significantly predict lower quality scores–time overrun has a somewhat larger marginal effect on quality than cost overrun within this sample, magnitude $\beta_2 > \beta_1$. This implies that schedule pressures and the disruptions accompanying delays, such as rushed remedial work, overlapping trades, and poor quality supervision, more strongly degrade workmanship than direct financial overruns alone.

Practical Implications

- Early schedule control and proactive labor/resource planning can preserve quality even under cost pressures.
- Investing in quality assurance early may reduce both rework and downstream schedule drag, thereby indirectly limiting cost overruns.
- Project managers should monitor combined critical to quality (CTQ) indicators, rather than isolated KPIs.

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- *Literature comparison*: The findings presented correspond with those of Josephson and Hammarlund (1999) and subsequent empirical work relating rework and defects to time and cost penalties. The magnitude of the effects here (0.4 and 0.6 quality points lost per 1% overrun) provides a concrete benchmark for practitioners to quantify trade-offs when making decisions.

CONCLUSION

The research empirically illustrates that cost, time, and quality in construction projects are interlinked dimensions rather than isolated performance indicators. The analysis confirms that cost overruns and schedule delays are highly related to variations in quality, meaning that deviations in one dimension tend to affect the others. More specifically, both cost overrun (%) and time overrun (%) emerged as statistically significant predictors of poor quality performance, which supports the long-held assumption in construction management literature that poor planning and control in the early stages of a project cascade into quality issues upon execution.

Of the two predictors, schedule delay exhibited a stronger marginal effect on quality deterioration. This supports the fact that time pressures, rushed activities, and compressed sequences of work intensify the likelihood of defects, rework, and non-conformance. This indicates a crucial role for time management in ensuring desired quality levels, particularly in labor-intensive construction environments.

The integrated CTQ modeling approach presented in this study provides a holistic view for project managers. The research findings present evidence-based views through the quantification of interactions using correlation and regression tools, which potentially assist in early risk identification, proactive resource allocation, and closer monitoring of project performance. The results also emphasize an organization’s need to adopt unified performance dashboards and cross-dimensional planning instead of having cost, schedule, and quality as separate reporting lines.

In conclusion, this research confirms that high-quality output can only be achieved by balancing control in all three constraints within the project triangle. Controlling deviations in cost and time is not only profitable but also a critical step toward quality assurance. The CTQ approach is thus practical for enhancing project predictability, reducing rework costs, and generally improving project delivery effectiveness.

Recommendations for Practice

Integrated CTQ Dashboard: Implement a dashboard that simultaneously tracks cost overrun %, time overrun %, and leading quality indicators (defect counts, inspection pass rates, and near misses).

Early quality assurance (QA) investment: Allocate budget for targeted early inspections, the return on investment (ROI) is lower rework and fewer schedule disruptions.

Schedule buffering for high-risk activities: Add contingency in critical path activities where quality risks are high to avoid rushed remedial work.

Use predictive models: Employ regression or machine learning models as early-warning systems and flag projects where predicted quality falls below acceptable thresholds given projected overruns.

Contractual incentives: Consider incentive schemes that reward adherence to all three CTQ dimensions.

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