

# Employment of Mathematical Statistics in Civil Engineering and Its Role in Statistical Quality Control in Construction Projects

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**Abstract.** Mathematical statistics plays an integral role in the current state of civil engineering applications. This paper discusses the application of statistical approaches in the improvement of planning and execution processes in the context of construction activities. Practical applications include cost analysis and risk assessment. By using an analytical and inductive approach based upon existing research studies published in reputable sources, the paper illustrates the author's point that the combination of statistical approaches improves the quality of output and leads to the reduction of variations regarding the analysis of civil engineering applications. This paper represents the author's personal research analysis and findings based upon the verification of established statistical principles.

**Keywords:** mathematical statistics; civil engineering; construction engineering; quality control; construction projects.

## 1. Introduction

The construction sector is increasingly beset by complexity introduced by technological advancements, interaction among factors, and increased demands for quality, safety, and sustainability. Deterministic methods have proven incapable of properly addressing uncertainty related to variability in materials, costs, and process instabilities. The construction sector thus requires analytical methods to improve planning, execution, and control processes.

Regarding a technical perspective on civil engineering, the basis for carrying out this research project lies in the many difficulties that have frequently been encountered in the field of construction projects in respect to their quality and costs. Such difficulties are generally related to variabilities in construction material, difficulties in estimating costs, as well as a lack of statistical application in construction projects.

Mathematical statistics: Mathematical statistics can play an important role in construction data analysis. Descriptive statistics, regression analysis, and statistical quality control are some of the tools of statistics that have been extensively used in industrial applications. But their application in construction engineering has not been significant.

Individual statistical approaches in construction were found to be successful by previous researchers in the context of cost estimation and quality control processes in construction projects. However, the

majority of the previous researchers consider the techniques in construction in an isolated manner without suggesting an overall approach that combines the construction processes of quality material assessment, cost estimation, and control of processes in construction projects.

Owing to the rising issues and challenges associated with uncertainty, variability of quality, and cost rise in construction projects, there has been a growing effort by researchers to use mathematical statistics. The next subtopic gives a brief overview of the various studies carried out concerning the use of statistics in civil engineering and construction management.

The contribution of this research lies in the presentation of an integrated statistical framework that connects the assessment of material quality, cost estimation, and control processes in the context of a construction project.

### *1.1 Related Work and Literature Review*

The important role of mathematical statistics in improving construction projects in terms of quality control, cost control, and risk management has been emphasized in the current literature. Statistical models have been widely used to handle variability in construction materials and optimize construction projects' cost and processes. Love et al. (2018) were able to demonstrate the effectiveness of Statistical Process Control in preventing cost overruns and rework in major infrastructure projects [1]. Similarly, the use of regression models in statistical cost estimation was emphasized by Zhao et al. (2019) in increasing the reliability of construction projects cost [2]. In the authors' views, the effect of statistical processes in construction projects cannot be overemphasized; rather, their application is limited and in practice is often piecemeal in nature. Some researchers have given adequate attention to Statistical Quality Control in construction projects. Oakland (2014) and Montgomery (2013) were able to demonstrate the important role of control charts and process capability in understanding construction material variability in terms of the strength of concrete materials [3,4]. However, the beneficial effect of Statistical Quality Control in developing construction projects in terms of the rate of adherence and material material wastage has been conveniently demonstrated by Hwang et al. (2020) [5]. Similarly, the current trend in the use of statistical models in relation to cost estimation of construction projects without using M.L algorithms is of great interest in understanding current construction projects practices. Kim et al. (2004) [6] were successful in explaining the difference in the reliability of results using regression models in statistical cost estimation in terms of cost compared with the construction cost practices in the industry using control charts with Montgomery's (2013) control charts in terms of material strength with adequate prediction models of cost estimation practices of construction projects with an explanation that statistical models perform better in construction cost estimation practices in terms of cost compared with the current review topic using Statistical processes in construction projects practices if the results of the current review topic were entirely different in practice.

## **2. Research Problem and Objectives**

### *2.1 Research Problem*

Despite the advancements being made in the construction industry through technology, quality discrepancies, delivery delays, and cost overruns continue to be encountered by many projects. One of the main reasons that add to these problems is the limited and disjointed use of statistical tools in the planning and control of the construction industry. Despite the success that has been experienced through the application of statistical tools in the industry in relation to construction-related research, their use has been sporadic. Many of the studies that exist were focused on individual tools and not as an overall approach where material quality assessment, cost estimation, and statistical control processes were incorporated. This has formed the reason for the current study.

## 2.2 Research Objectives

- To emphasize the role of mathematical statistics in civil engineering.
- To examine the use of statistical concepts in construction activities.
  - To evaluate the use of statistics in statistical quality control.
- For the adoption of statistical methods in the management of construction.

## 3. Research Methodology

For the purposes of conducting this research work, the model used is analytical and inductive in nature. This is based on a structured literature review and examples of statistical analysis chosen by the author. Furthermore, the approach taken in the work is divided into three main parts. First, the literature review highlighted the range of applications which have been made using statistics in the discipline of construction engineering. A second stage is the analysis of the data sets mentioned in the literature which relate to the construction industry. This analysis was carried out using descriptive statistics, linear regression analysis, and statistical quality control.

### 3.1 Statistical Methods and Formulations

To supporting the analysis framework of this research, appropriate statistical analysis tools were used for dealing with issues of variability, relationships, and process stability. In the next subsection, mathematical expressions for descriptive statistical analysis, regression analysis, and statistical quality control procedures are described.

Mean:

$$\bar{x} = (1 / n) \Sigma x_i \quad (1)$$

Standard Deviation:

The above equation defines  $\sigma$  as:

$$\sigma = \sqrt{[(1 / n) \Sigma (x_i - \bar{x})^2]} \quad (2)$$

These factors were employed to evaluate the variation in the compressive strength of concrete and to set control limits in Statistical Quality Control. For the cost estimation, the linear regression model was used:

$$Y = \beta_0 + \beta_1 X + \varepsilon \quad (3)$$

where Y is the cost of the projects, X is the area of the buildings constructed,  $\beta_0$  and  $\beta_1$  are the regression coefficients, and  $\varepsilon$  is the error term in the models. The models' goodness of fits were assessed using the coefficient of determination ( $R^2$ ) because the values showed the respective proportions of the models' variations that were explained by the models. The statistical models proposed were chosen for being commonly used and dependable in the control of quality in civil construction projects. 4. Theoretical Framework Mathematical statistics includes descriptive statistics, probability distributions, regression analysis, hypothesis testing, and control charts. In the engineering of construction projects, these techniques must be applied in relation to the analysis of concrete strength variations, the estimation of the cost of projects, and the control of processes related to quality. This is shown in \*Fig. 1\* as the conceptual framework.

## 4. Theoretical Framework

Mathematical statistics include descriptive statistics, probability distributions, regression analysis, hypothesis testing, and control charts. In the area of construction engineering, the use of these methodological frameworks is essential in discussing the variability of concrete strength materials in the industry. Figure 1 illustrates the conceptual framework which links the methodological frameworks in statistical analysis and the performance in construction projects.

Figure 1 illustrates the conceptual framework where statistical analysis methods are related to project performance in construction.



Figure 1. Conceptual framework illustrating the relationship between statistical methods and construction project performance.

## 5. Applications in Construction Engineering

### 5.1 Material Quality Analysis

Analysis of material quality uses descriptive statistics to evaluate the results. In the case of compressive strength determination in concrete, the use of means and standard deviations gives an indication of the results' consistency and conformance. The example given is a simple but practical case of concrete strength determination.

**Table 1.** Concrete Compressive Strength Test Results.

Sample	Strength (MPa)
1	28
2	32
3	29
4	30
5	32
Mean (MPa)	30.2
Std. Dev (MPa)	2.1

### 5.2 Cost Estimation Using Regression Models

Regression analysis is widely used for construction cost estimation for correlating project variables with costs. Linear regression models allow project managers to estimate costs based on important variables such as building area. Correlation between building area and project cost can be established for a regression model, as shown in Figure 2.

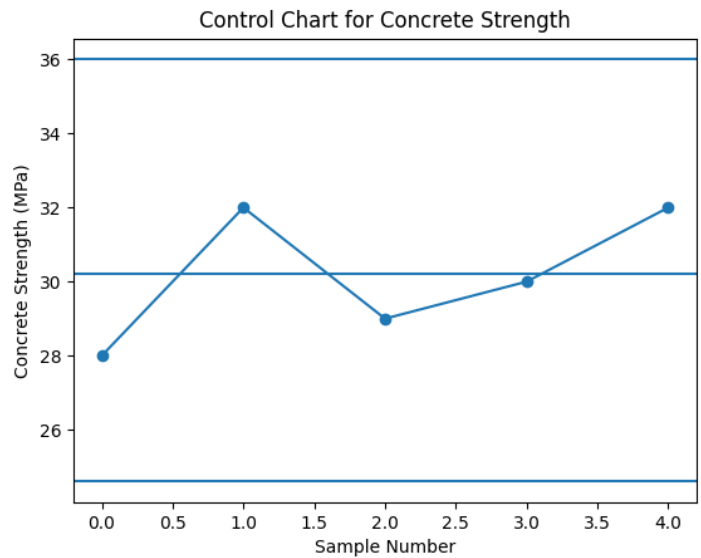


Figure 2. Regression plot showing the relationship between building area and project cost.

### 5.3 Control of Construction Variability

Methods from statistical quality control, such as control charts, are used for the monitoring of construction processes as well as the detection of abnormal variations. These help in the preventive management of quality.

## 6. Statistical Quality Control (SQC)

Statistical quality control provides engineers with an organized approach in the measurement and control of construction quality. Through the establishment of control limits that are statistical in nature, engineers are in a position to distinguish between natural variations in processes and deviations that require action. Variations in the compressive strength of concrete were measured using the control chart in Figure 3.

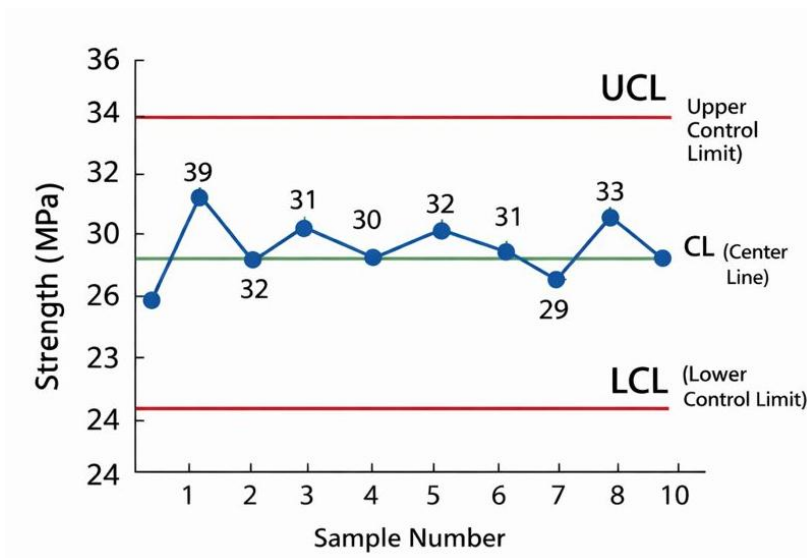


Figure 3. Control chart illustrating concrete compressive strength with upper and lower control limits.

The process for improving quality continually, as used in the construction industry, is shown in Fig. 4.  
 Figure 4: Quality control cycle in the construction industry

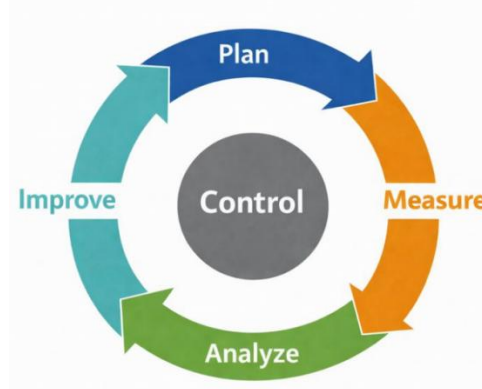


Figure 4. Quality control cycle applied in construction projects.

### 7. Results and Discussion

The statistical tools described in the previous sections were used by the author on selected data from the construction area in order to test their effectiveness in improving quality control and cost estimation. The result outline the effect of the application of mathematical statistics in the construction area in order to offer an insight into its role in constructing improved projects. The result from the concrete compressive strength test showed the mean value to be 30.2 MPa with the standard deviation at 2.1 MPa. The coefficient of variation was seen to be roughly 6.95%. The result shows low variability, which supports the idea that the process of material creation is normalized and fits the quality criteria. The result from the graph was in line with the expectation from a controlled environment such as the concrete laboratory. The result from the graph also indicated that the coefficient of determination (R-squared) was roughly 0.97; the result implies that the variable of building area was the main factor affecting the other variable, which was the total cost of the building. The coefficient of determination implies that the model was effective in predicting the early stages of the total building cost. The total result indicated that all the strength values were in the defined boundaries, which implied that the processes in the construction area were under statistical control. The result indicated that the total strength values were not out of control, which implies that quality in the construction area can be controlled in advance through the application of quality statistics.

### 8. Limitations of the Study

Despite the application value of the statistical framework proposed, the study has some limitations. The research is based on representative data and not on the actual project data. This may hinder the generalizability of the study towards all construction projects. However, the main point is to present the application of statistical processes in the field of construction engineering.

### 9. Conclusion

This research verifies the importance of mathematical statistics in optimizing the efficiency of construction projects. The author recommends applying mathematical statistics in construction and civil engineering. Further exploration of this concept could be done by implementing this framework on real construction projects and applying modern mathematical statistics. The above research has been carried out by independent analysis and interpretation by the researcher based on the existing literature on construction and mathematical statistics. In light of the above analyses carried out and based on the independent judgment of this researcher as a civil construction expert and academic, mathematical

statistics can offer effective tools and methods in enhancing construction project efficiency. The above framework aims to represent expert judgment on how mathematical statistics can be applied to construction project efficiency.

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