# FORECASTING THE COST AND DURATION OF SCHOOL RECONSTRUCTION PROJECTS USING REGRESSION ANALYSIS

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**ABSTRACT:** This paper collected 132 schools reconstruction projects in central Taiwan, which received the most serious damage from the Chi-Chi Earthquake. Regression analysis was implemented to build the prediction model of the cost and the duration for the collected projects. It is found that the cubic regression models are capable for predicting the cost and the duration of the projects contracted by the central agency of which the contracting awarding approach was based on the most advantageous tendering (MAT) approach. On the other hand, power regression models are capable for predicting the cost and the duration of the projects contracted through the low bid tendering (LBT) approach. It is also found that the performance of the regression prediction model differs in accordance with organizations that contracted the reconstruction projects.

*Key words : Cost and duration, Reconstruction project, Regression analysis*

## 1. INTRODUCTION

In the early morning of September 21st, 1999, a large earthquake measured 7.3 on the Richter scale struck the island of Taiwan near the centrally located city of Chi-Chi. The quake, called the 921 or Chi-Chi Earthquake, and its aftershocks caused 2,455 deaths, 8,000 injuries and the destruction of 38,935 homes.

During the four years recovery period, reconstruction of damaged or destroyed infrastructure facilities, such as roads, bridges, public buildings, schools and residential buildings in a short time and under the limited resources and budgets was the primary concern of the whole society. One major difficulty was to estimate accurately the duration and cost of the reconstruction projects in the early planning phase without detailed information and under limited time pressure, particularly for those personnel without adequate engineering background or experience. Therefore, this study attempts to build a simple estimation model for school-reconstruction projects to estimate the reconstruction duration and cost to assist decision-making for any emergency situations.

Relationships among construction cost, project duration, and other significant factors have been investigated for building projects, but few studies have been performed concerning building reconstruction projects. Bromilow examined building projects in Australia and found a relationship between construction cost and project duration [1,2]. The following studies have been performed by Ireland [3] and Walker [4], along with the National Economic Development Office (NEDO) in the UK [5]. Kumaraswamy and Chan found that other factors, such as the time-floor area relationship, may significantly affect project duration [6]. Chan studied the time-cost relationship of building projects in Hong Kong and Malaysia, respectively, and found that it served as a convenient tool to predict the average time required for delivery a construction project [7,8].

More literature has been discussed about challenges and problems faced by the reconstruction projects [9,10,11], but few have concentrated on the relationship among reconstruction cost, project duration and other factors.

## 2. SCHOOL RECONSTRUCTION PROJECTS

As a result of the Chi-Chi Earthquake, 1,546 schools were quake-damaged, including 293 that were almost completely destroyed. To save time, the school reconstruction projects were planned and contracted through both the public and private sectors. The public sector organizations include the central agency (Construction and Planning Agency, the Ministry of the Interior, entrusted by the Ministry of Education), and the local governments controlling the damaged schools. The contract-awarding approaches of the public sectors are either the Lowest Price Tendering approach (LPT) or the Most Advantageous Tendering approach (MAT) based on the Government Procurement Law (GPL) in Taiwan.

The GPL was enacted on May 27, 1999 to establish a government procurement system with fair and open procurement procedures to encourage efficient and effective government procurement operation as well as to ensure procurement quality. Based on GPL open tendering procedures, a public notice is issued to invite all interested suppliers to submit their bids. Using the LPT approach, a qualified bidder with the lowest bid price within the client estimate is awarded the contract. If a client estimate is not established for the procurement, then a qualified bidder, which has a reasonable price as reviewed by a procurement committee and is also the lowest tender within the budget amount, shall be awarded. Another contract-awarding approach, MAT, chooses the best-qualified contractor without using the lowest cost tendering scheme. If MAT is applied by a procurement entity, the best-qualified bidder is awarded the contract. Within the MAT approach, the evaluation criteria presented in the tender documentation may include the technology, quality, function, commercial terms or price of the bids. If the bid price is among the evaluation criteria, the weight of the bid price must not exceed 50% of all criteria [12]. In the school-reconstruction projects, the award of the central agency contract was based on the MAT as well as the fixed price approach, to shorten the reconstruction schedule. The local governments principally applied the LPT approach.

The private organization putting efforts on reconstructions are charity groups mostly, such as Tzu Chi Foundation and the Lion Clubs International. These organizations awarded contracts principally to the lowest bidder. Unlike the central agency and local governments, the procurement procedures of these private organizations are not restricted by the GPL; thus, the planning and contracting of the reconstruction projects is more flexible for private organizations than for public organizations.

## 3. DATA COLLECTION AND ANALYSIS

This research collected 132 reconstruction projects of the elementary and preliminary schools in Nantou County, which received the most serious damage from the Chi-Chi Earthquake. At least one building collapsed in each of those schools during the Chi-Chi Earthquake. Based on the planning and contracting agency, these reconstruction projects were classified into three categories: the central agency, the local government and the private sector, as mentioned above. Among these projects, 34 were contracted by the central agency, 44 by the local government, and 54 by the private sector. Table 1 summarizes the information of collected projects.

**Table 1.** Information collected from reconstruction projects

| Category | Central Agency | Local Government | Private Sector |
|---|---|---|---|
| Sample Size | 34 | 44 | 54 |
| Duration (Day) | 90 ~ 380 | 65 ~ 259 | 135 ~ 493 |
| Cost (Thousands Dollar) | 470.6 ~ 7,826 | 7.6 ~ 1,389 | 91 ~ 6,172 |
| Floor Area ($m^2$) | 512 ~ 19,930 | 21 ~ 4,499 | 1,419 ~ 20,053 |

The software of Statistical Package for Social Science (SPSS) was applied to compute the correlation coefficient for every linear relationship between each variable. Table 2 shows the correlation among three variables, duration, cost and floor area. The correlations between duration and cost, and between duration and floor area were found to be similar. For reconstruction projects contracted by the central agency, the correlation coefficients between duration and cost, and between duration and floor area, were found to be closed with the values of 0.809 and 0.849, respectively. Similar situations were found for reconstruction projects contracted by the local government or the private sectors. For the previous projects, the correlation coefficients between duration and cost, and between duration and floor area were found to be around 0.75. For the last projects, the correlation coefficients between duration and cost, and between duration and floor area are around 0.4. These analytical results also illustrated the relationships of high correlations between duration and cost, and between duration and floor area, for reconstruction projects contracted by the governments, the central agency and local government. For reconstruction projects contracted by the private sectors, the relationships between duration and cost, and between duration and floor area, are medium correlation with correlation coefficients around 0.4, indicating a possible nonlinear relationship between them.

The results also reveal that the correlation coefficients between cost and floor area are around or above 0.9 regardless of the project's category. This finding demonstrates a relationship of high correlation between cost and floor area.

**Table 2.** Correlations among variables for reconstruction projects

| Category | | Variables | | |
|---|---|---|---|---|
| | | Duration | Cost | Floor Area |
| Central Agency | Duration | 1 | 0.809 | 0.849 |
| | Cost | 0.809 | 1 | 0.966 |
| | Floor Area | 0.849 | 0.966 | 1 |
| Local Government | Duration | 1 | 0.744 | 0.760 |
| | Cost | 0.744 | 1 | 0.910 |
| | Floor Area | 0.760 | 0.910 | 1 |
| Private Sector | Duration | 1 | 0.400 | 0.430 |
| | Cost | 0.400 | 1 | 0.893 |
| | Floor Area | 0.430 | 0.893 | 1 |

## 4. MODEL DEVELOPMENT AND VALIDATION

Ten percent of collected sample projects for each category were selected randomly and set aside for validation, while the rest were employed for model building. The data sets were applied to develop the regression mode. For developing the regression model, the following regression models were investigated to identify the best format for this study: linear equation (LIN), logarithmic equation (LOG), inverse equation (INV), quadric equation (QUA), cubic equation (CUB), composite equation (COM), power equation (POW), S-curve equation (S) and exponential equation (EXP). Table 3 presents the basic forms of the equations for these regression models, where *X*, $X_1$ and $X_2$ denote the independent variables; *Y* denotes the dependent variable, and $b_0$, $b_1$, $b_2$ denote constants.

**Table 3.** Equation forms of regression models

| Regression Model | Regression Equation |
|---|---|
| Linear Regression (LIN) | $Y = b_0+b_1 * X$ |
| Logarithmic Regression (LOG) | $Y = b_0+b_1 * \ln X$ |
| Inverse Regression (INV) | $Y = b_0+b_1/ X$ |
| Quadric Regression (QUA) | $Y = b_0+b_1 * X + b_2 * X^2$ |
| Cubic Regression (CUB) | $Y = b_0+b_1 * X + b_2 * X^2 + b_3 * X^3$ |
| Composite Regression (COM) | $Y = b_0 * b_1^x$ |
| Power Regression (POW) | $Y = b_0 * X^{b_1}$ |
| S-Curve Regression (S) | $Y = e^{(b_0+b_1/X)}$ |
| Exponential Regression (EXP) | $Y = b_0\, e^{(b_1 * X)}$ |

### 4.1 Cost Prediction Model

In the cost prediction model, the floor area was chosen as the independent variable. Table 4 presents the $R^2$ values of each regression function for cost prediction, and shows that for the school reconstruction projects contracted by the central agency, the cubic regression equation (CUB) is the most appropriate cost prediction model, with a squared multiple R of 0.947. For the projects contracted by local government or the private sector, the power regression equation (POW) is more suitable than other regression questions. Table 5 shows each category's regression model for cost prediction, where *A* denotes the floor area in $m^2$, and *C* denotes the cost in Dollar. The analytical results show that floor area predicts well the cost of school reconstruction projects.

The results also show that power regression equation (POW) models well the relationship between cost and floor area for reconstruction projects contracted through the lowest bid system, as employed by the local government and the private sectors. For reconstruction projects contracted though the MAT approach, the relationship between cost and floor area may be better modeled by the cubic regression equation.

**Table 4.** $R^2$ of regression equations for cost prediction

| Regression Model | Organization Category | | |
|---|---|---|---|
| | Central Agency | Local Government | Private Sector |
| LIN | 0.828 | 0.823 | 0.798 |
| LOG | 0.773 | 0.704 | 0.710 |
| INV | 0.483 | 0.185 | 0.656 |
| QUA | 0.828 | 0.864 | 0.724 |
| CUB | **0.947** | 0.878 | 0.774 |
| COM | 0.850 | 0.631 | 0.481 |
| POW | 0.876 | **0.897** | **0.835** |
| S | 0.692 | 0.513 | 0.610 |
| EXP | 0.850 | 0.631 | 0.481 |

**Table 5.**. Regression model for cost prediction

| Category | Model Type | Regression Model |
|---|---|---|
| Central Agency | CUB | $C = 1235963.38 - 120.99 * A + 0.06 * A^2 - 2E^{-6} * A^3$ |
| Local Government | POW | $C = 1139.07 * A^{0.8589}$ |
| Private Sector | POW | $C = 2878.31 * A^{0.7750}$ |

### 4.2 Duration Prediction Model

Two independent variables, cost and floor area, were addressed respectively as the independent variable in the regression equations to forecast the duration of school reconstruction projects. Table 6 summarizes the largest $R^2$ of the regression models using these two independent variables. The analytical results demonstrate that for reconstruction projects contracted by the central agency or the local government, using floor area as the independent variable in the regression model can reach a higher square multiple R; conversely, for projects contracted by the private sector, using cost as the independent variable can provide a better result. Table 7 shows the regression models for predicting duration for each category, where $A$ denotes the floor area in $m^2$; $C$ denotes the cost in Dollar, and $T$ denotes the duration in days.

As shown in Table 7, the regression models with cubic equations best predict the duration of the reconstruction projects contracted by the central agency. For projects contracted by the local government or the private sector, regression models using power equations are the most accurate for modeling the duration. These results were the same as those found when developing the cost prediction model, and demonstrate that the choice of contract-awarding method may affect the cost and the duration of a reconstruction project; therefore, choosing different prediction models in different contract-awarding approaches is necessary to achieve better prediction results.

The above findings agree with the time-floor area relationship ($T=LA^M$) developed by Kumaraswamy and Chan [6], and the time-cost formula ($T=KC^B$) developed by Bromilow [2], respectively, where T denotes the construction time; A denotes the area; C denotes the project cost, and L, M, K and B denote the coefficients. These relationships indicate that the time-floor area relationship or the time-cost formula cannot only be applied to the building projects, but also to building reconstruction projects. This study shows that these relationships can be applied to the school-reconstruction projects contracted through the lowest bid approach.

**Table 6.** $R^2$ of regression equations for duration prediction

| Category | Independent Variable | | | |
|---|---|---|---|---|
| | Floor Area | | Cost | |
| | Model Type | $R^2$ | Model Type | $R^2$ |
| Central Agency | CUB | **0.750** | CUB | 0.721 |
| Local Government | POW | **0.657** | CUB | 0.618 |
| Private Sector | S | 0.270 | POW | **0.608** |

**Table 7.** Regression models for duration prediction

| Category | Model Type | Independent Variable | Regression Model |
|---|---|---|---|
| Central Agency | CUB | Floor area | $T = 131+0.018*A - 1.085E^{-6}*A^2 + 3.675E^{-11}*A^3$ |
| Local Government | POW | Floor area | $T = 42.280*A^{0.1966}$ |
| Private Sector | POW | Cost | $T = 108.458*C^{0.2058}$ |

### 4.3 Model Validation

Ten percent of the collected sample projects were adopted for model validation. Table 8 shows the average percentage error for each regression prediction model. The analytical results show that the regression prediction model provides a better capacity in predicting the cost and duration of reconstruction projects contracted by the central agency than those contracted by the local government or the private sectors.

**Table 8.** Average percentage error for regression prediction model

| Category | Sample size | Average Percentage Error | |
|---|---|---|---|
| | | Cost Prediction Model | Duration Prediction Model |
| Central Agency | 4 | 9.01 | 7.80 |
| Local Government | 5 | 17.17 | 15.75 |
| Private Sector | 6 | 14.45 | 13.82 |

## 5. CONCLUSIONS

This study concentrates on school reconstruction projects in central Taiwan, which received the most serious damage from the Chi-Chi Earthquake. Based on data gathered from the reconstruction projects, cost and duration prediction models for these reconstruction projects were developed. Regression analysis was used to build the cost and duration prediction models for the school reconstruction projects.

The regression prediction models show that floor area estimates well the cost and the duration of these reconstruction projects. As the results indicated, the cubic regression models can forecast the cost and duration of the reconstruction projects contracted by the central agency, where MAT was used to award contracts. Conversely, power regression models can predict the cost and duration of the reconstruction projects contracted through the lowest bid approach, which was implemented by the local government and the private sectors principally.

The regression prediction model performance differs based on the organizations that contracted the reconstruction projects. For reconstruction projects contracted by the central agency, the regression models produce good prediction results with average error rates below 10%. However, the average error rates increase to around 15% when predicting the cost and duration of reconstruction projects contracted by the local government or the private sectors.

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