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Measuring the Impact of Change Orders on Project Performances by Building Type

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Abstract: The project performances can be measured in terms of meeting the project schedule, budget, and conformance to functional and technical specifications. Numerous studies have been conducted to examine the causes and effects of change orders for both vertical and horizontal construction, respectively. However, these studies mainly focus on a single project type, so this paper examines the impact of change order for cost growth and schedule overruns using four different building types to close the gap in the change order research area. A total of 211 building projects are collected from four building types: healthcare, residential, office, and education. Statistical analyses using ANOVA tests and linear regression models are used to examine the created metric $CO/day on the cost and schedule impacts. The results found that mean $CO/day values were not statistically different among building types, and that the sum of change orders is a statistically significant predictor of $CO/day. The results will help project stakeholders mitigate the negative change orders effects can be a challenge for project managers and researchers alike.

Key words: Change orders, Building construction, Cost, Schedule, Statistics

1. INTRODUCTION

The timely completion of construction projects is paramount to the overall success of the project. Proper scheduling of project tasks provides economic benefit from the outset of the project by ensuring that no unnecessary time is wasted that may contribute to inflated labor costs. In addition, optimized scheduling also provides the best economic benefit, as quickly completed projects are able to be utilized in their intended manner as soon as possible. Similarly, accounting for all materials necessary to the project and their costs ensures that no excessive costs are incurred. However, despite the effort put forth by planners and engineers, initial project scopes are often altered after a project's beginning. Koch et al. (2010) explained that these changes are often a result of the complicated and distinctive nature of construction projects. Other factors include communication errors, preference changes, or unforeseen conditions. In any event, it is impossible to account for every single eventuality that may occur throughout the lifetime of a project.

Adjustments in a construction project are typically manifested as change orders, which are generally described as any sort of alteration of a project's scope that results in a change (modification, addition, deletion) of an item in a construction contract. According to Syal and Bora (2016), change order proposals are submitted to construction managers by the subcontractors of a given trade (masonry, plumbing, etc.) at the initial behest of the property owner or project designers. All aforementioned parties are involved in the authorization of change orders. Change orders typically have negative effects on overall project performance, in terms of excess time and money, as is echoed in the literature. Sometimes change orders can cause issues among the project stakeholders. In these cases, claims can be made by a project stakeholder to recuperate lost time and/or expenses incurred by the issuance of a change order (Mehany et al. 2018). For the above reasons, change orders are generally avoided if possible or their negative effects are mitigated.

The body of literature on the subject of change orders is fairly large and covers a wide array of construction projects viewed from different angles. Most commonly, studies are focused on either the construction/renovation of buildings or transportation projects. Kim et al. (2020) analyzed 517 change orders from 27 building renovation projects to compare the cost impact of change orders caused by unforeseen circumstances and those caused by all other reasons. The study found that change orders from unforeseen circumstances and those caused by all other reasons were not statistically different using t-test analysis. Shrestha and Fathi (2019) examined change order data from 125 building projects to analyze design-build (DB) and design-bid-build (DBB) projects. Results from t-tests and correlation tests in the study indicated that the relationship between project size and the number of change orders is similar for DB and DBB projects, although the two categories differ when considering the impact of change orders on cost and scheduling. Ahmed et al. (2016) used regression to create a model to predict the cost of change orders based on original construction cost and identify the most important causes of change orders across 40 projects in Syria. Similarly, Khalafallah and Shalaby (2019) created a framework to easily visualize and analyze the causes of change orders and the impact of different factors on change order cost and time using a proprietary model implemented in a database management system.

In the field of transportation, research is primarily focused on roadway construction projects. Alleman et al. (2020) triangulated change order data from 162 highway projects in the US to determine the most impactful change order categories, which were found to be those caused by unforeseen conditions. Taylor et al. (2012) studied change orders from 610 roadway projects in Kentucky to examine how causes of change orders varied among new construction and maintenance projects. Using a combination of ANOVA tests and other methods such as the application of graphic information systems, the study supported the claim that high-risk change orders can be avoided through improved project planning. Shrestha et al. (2017) focused on the effects of change orders on both cost and scheduling of rural road maintenance projects. Using nonparametric Kruskal-Wallis H test and correlation tests, the study showed, among other things, that as change order percentages increased, scheduling was greatly affected. Similarly, Shrestha et al. (2018) again examined the cost and schedule growth of highway projects, although the focus was now placed on large projects. Based on data from 185 projects in the state of Texas, the results of t-testing and correlation tests indicated that change order growth is moderately correlated with cost growth and schedule growth.

2. RESEARCH OBJECTIVE AND METHOD

Change orders are a heavily researched topic and adding to the expansive field is important to the understanding of how to mitigate negative effects. Little research has been conducted to examine the effect of the building type on the negative impacts of change orders, such as increased costs and delayed scheduling. This paper seeks to add to this body of research by completing two objectives. First, the effects of change orders on project cost are compared across different building types. Four different building types such as healthcare, residential, office, and education buildings are considered due to the availability of change order data and the projects are mainly located in California. Second, models for each building type, in addition to a combined model for all building types, are built to analyze the effect the amount of change orders has on potential cost impact. Determination of any statistical difference between the potential cost impacts among building type will determine if higher costs are incurred for certain project types. Figure 1 shows the schema of the research methodology. Statistical methods are used to examine the effect that a building type has on the cost impact of change orders. First, ANOVA analysis is used to compare mean cost incurred by change orders issued among different building types. This will determine if one building type has higher costs associated with it as compared to others at a statistically significant level. Then, linear models for each building type are constructed to examine if a relationship exists between the number of change orders issued for a project and the potential cost impact of the change orders. Finally, a combined linear model is created to examine the combined effect of number of change orders and building type on potential cost impact on the entire dataset.

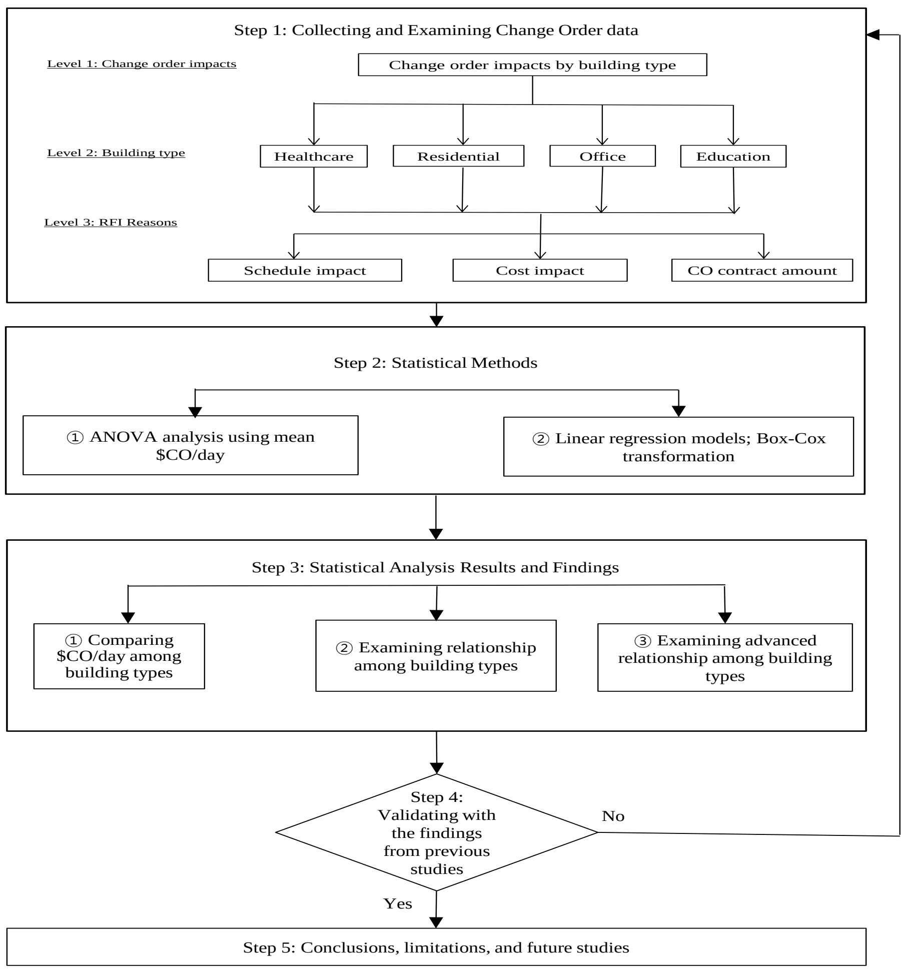

Figure 1. Schema of the research methodology

3. DATA COLLECTION

Data for this paper were collected from change orders issued from various construction projects done from 2010 through 2019. A total of 211 projects with a combined 71,055 change orders were examined. The data are organized by the four building type categories such as healthcare, residential, office, and education. The data include the potential schedule impact (in number of days) of the change orders, the potential cost impact, and the current change order contract amount. To avoid bias, the potential cost impact was divided by the potential schedule impact, since it is reasonable to assume that higher costs will be associated with a greater amount of days. A better predictor of increased cost from change orders, such as project square footage as used in Kim et al. (2020) would have been used for analysis. However, it was thought this method would suffice, as change orders could be compared across differently impacted schedules. Thus, the metric denoted as $CO/day is the primary focus of the paper for ANOVA testing and linear regression modeling.

4. ANALYSIS AND FINDINGS

Descriptive statistics were aggregated for each building type for project sums, change order sums, and average change orders per project to aid in the understanding of which building types incur the most total change orders and change orders per project. Similarly, descriptive statistics were generated for $CO/day to analyze cost impacts of change orders. Table 1 displays the quantity and frequency by building type. In order of descending frequency, the building types with the most projects are healthcare, office, education, and residential, with frequencies of 35.07%, 34.6%, 19.43%, and 10.9%, respectively. Similar results are found when comparing the frequencies of change order sums among building types, with values of 38.27%, 33.66%, 18.92%, and 9.16% for office, healthcare, education, and residential, respectively. This result is expected, as a higher number of projects within a building type leads to a higher number of change orders. Because the difference between project quantity frequency and change order sum frequency is within ±4% for all building types, the frequency of change orders per project sum is also examined. For all building types, this metric was similar, with no value below 21% and none higher than 29%. This result indicates that all building types incurred about the same number of change orders per project.

Table 1. Quantity and frequency of projects and change orders by building type

Building Type	Sum of projects	Percent of Projects (%)	Total sum of COs	Percent of COs (%)	CO/Project	Percent of CO/Project (%)
Healthcare	74	35.07	23915	33.66	323.2	24.74
Residential	23	10.90	6507	9.16	282.9	21.66
Office	73	34.60	27191	38.27	372.5	28.51
Education	41	19.43	13442	18.92	327.9	25.10
Totals	211	100	71055	100	-	100

Table 2 shows the change order contract amount range and the average potential cost increase incurred by the change orders in each range. This percentage was calculated based on the average change order contract amount for each range within each building type. For healthcare, the most projects occur in the $1 million to $10 million change order contract range, with projects being spread fairly evenly in the other ranges. Projects with lower current change order contract amounts are clearly more affected by the potential cost increases associated with the change orders, as percentages significantly drop off after the $1 million mark from 1286% to 77%. For residential buildings, the majority of projects reside in the $2 million to $80 million range for CO contract amount. Overall, residential buildings appear to have the highest change order contract amounts per project. Similar to healthcare, the average potential cost increase value decreases with increasing CO contract amount. Office buildings and education show similar results as the other two building types. The average potential cost increase results are not altogether surprising, as low CO contract ranges will inevitably correspond with higher potential cost increases when measured in this way. What this indicates, however, is that the potential cost impact incurred by each sum of change orders is relatively high regardless of building type or number of projects.

Table 2. Quantity and frequency of projects by change orders contract range by building type

Building Type	CO Contract Range ($1000)	Sum of projects	Average Potential Cost Increase (%)
Healthcare	0 - 100	13	1296
	100- 1000	16	1286
	1000- 10000	31	77
	> 10000	14	43
Residential	0 - 2000	7	116
	2000- 80000	12	68
	> 80000	4	9
Office	0 - 100	9	2024
	100- 1000	24	325
	1000- 10000	26	81
	10000 - 100000	12	35
	> 100000	2	62
Education	0 - 1000	11	523
	1000- 10000	17	85
	10000 - 500000	9	11
	> 500000	4	2

4.1. Comparison of Change Order Cost Impact per Day by Building Type

ANOVA was used to compare $CO/day among building types. To execute ANOVA analysis, parametric assumptions must be met. Since data were collected across different years and building types, they are assumed to be independent. Bias was avoided by dividing the potential cost impact of change orders by the schedule impact in days. The next assumption to check is if the data are normally distributed. As an initial qualitative check of normality, histograms of $CO/day data for each building type showed that the data was bunched in the lesser bins, indicating that a log transformation might be useful. After log-transforming the data, normal probability plots were created using the Anderson-Darling normality test. For all building types, the results showed that the transformed data was not skewed along the line of normality, with p-values above the α=0.05 level, suggesting that the transformed data was normally distributed. The final assumption regards the data having equal variances. Bartlett's test was used on the transformed data since it was found to be normally distributed and resulted in a p-value of 0.976, which exceeds the α level. Since all parametric assumptions were verified, one-way ANOVA analysis proceeded.

The null hypothesis for the ANOVA test is that the mean potential cost impact due to change orders per day of potential schedule impact was equal for all building types. The alternative hypothesis is that at least two of the mean $CO/day values are different. Table 3 shows the descriptive statistics for the log-transformed data. The mean $CO/day for residential buildings is the highest at $13,867,082, followed by office, healthcare, and education buildings, in order of descending mean values. Table 3 also shows the ANOVA results to compare $CO/day among building types. As previously stated, the data had to be log-transformed to meet the parametric assumptions. A p-value of 0.267 was output from the test, which exceeds the significance level of $\alpha = 0.05$. Thus, insufficient evidence exists to reject the null hypothesis. This result implies that statistically speaking, the mean $CO/day values are not significantly different across each of the four building types. The fact that the means for all building types were found not to be statistically different from one another shows that the impact of schedule days combined with potential change order costs impacts cannot be ignored for both expensive and relatively inexpensive projects.

Table 3. Descriptive statistics and ANOVA test results for log-transformed data

(a) Descriptive statistics					
Source	**DF**	**Adjusted SS**	**Adjusted MS**	**F-value**	**p-value**
Factor	3	12.25	4.082	1.33	0.267
Error	207	637.23	3.078		
Total	210	649.47			

(b) ANOVA test results			
Building Type	**Number of Projects (n)**	**Mean $CO/day**	**Standard Deviation**
Healthcare	74	9.24	1.785
Residential	23	9.969	1.754
Office	73	9.171	1.696
Education	41	9.187	1.802

4.2. Linear Regression Model Building

The second objective of this paper is to create linear regression models which may describe the relationship between the potential cost impact per day ($CO/day) and the number of change orders for each project based on building type. Thus, the dependent (response) variable for each analysis done by building type was $CO/day and the independent variable was the sum of change order numbers. Because only one independent variable was involved in the building type regression models, simple linear regression was utilized. The null hypothesis (H_o) for these tests is that the slope (β_1) of the independent variable (sum of change order numbers) is equal to zero. The alternative hypothesis (H_a) is that β_1 is not equal to zero. In addition to the four individual models for each building type, an aggregate model was created using the combined data. This model continued to utilize sum of change order numbers as one of the independent variables, but it also used building type as a categorical predictor variable. As more than one predictor variable was used, multiple linear regression had to be performed. Similar to the simple linear regression models, the null hypothesis is that the slope of at all the independent variables is equal to zero, while the alternative hypothesis is that at least one is not equal to zero. By doing this, the combined model could examine the effect of building type on the mean cost impact per day, if such a relationship existed. As stated previously, the dependent variable ($CO/day) was found not to be normally distributed. Thus, in constructing the models the log transformed data was used so as to output residuals that conformed to the normal distribution. This was achieved via a Box-Cox transformation during analysis using $\lambda=0$. Because of this, the model coefficient outputs are essentially meaningless in their original context and therefore had to be interpreted properly. As previously stated, four linear regression models were constructed for each building type that related $CO/day to the number of change orders for each project. In addition, a combined model was built to test if building type was a significant predictor of $CO/day for the entire dataset.

The first four models take on the following form:

$$\ln\left(\frac{\$CO}{day}\right) = \beta_0 + \beta_1 x_1 + \varepsilon \quad (1)$$

, where x_1 is the predictor variable of number of change orders and ε is the error term. The results for β_0 and β_1 values for each building type are shown in Table 4, along with other parameters.

Table 4. Linear regression modeling results for individual building types

Building Type	β_0	β_1	% Increase Response	p-value	R^2 (%)
Healthcare	8.601	0.001977	0.198	0.000	20.83
Residential	9.274	0.00245	0.245	0.034	19.66
Office	8.469	0.001885	0.189	0.000	27.15
Education	8.778	0.001246	0.125	0.090	7.21

The results show that for all building types except for education, the p-value does not exceed the α=0.05 level, indicating that the null hypothesis can be rejected for these three types. In other words, the relationship between $CO/day and the sum of change orders is statistically significant for healthcare, residential, and office buildings. As mentioned, a Box-Cox transformation was used with λ=0 to take the natural log of the response variable. Because of this, the reported beta values need to be interpreted into something useful for analysis, particularly the slope, β_1. The fourth column of Table 4 gives the percentage increase of the dependent variable by every one-unit increase of the independent variable. While these rates are rather low, they give some indication as to how the addition of each change order affects the potential cost and schedule impact. The R^2 values indicate how much of the variation of the independent variable can be explained by each model. The low R values are a result of each model possessing a high number of unusual observations (outliers) which pull the model in one particular direction. However, the results are promising, as for three building types, the number of change orders is a significant predictor of $CO/day. This result seems obvious, but is important for project stakeholders, who need to minimize the number of change orders to simultaneously minimize the potential cost impact. The final model takes the following form:

$$\ln\left(\frac{\$CO}{day}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \varepsilon \quad (2)$$

, where x_1 is the sum of change orders, x_2, x_3, and x_4 are the categorical predictor variables for healthcare, office, and residential buildings, respectively, which have values of either zero or one depending on the inclusion of one or more of those building types in the model, and ε is the error term. Since the relationship between sum of change orders and $CO/day was not statistically significant in the previous analysis, education buildings were excluded from the combined model.

Table 5. Linear regression modeling results for three building types

	Term	Coefficient	% Increase Response	Standard Error Coefficient	p-value	VIF
	Constant	8.574		0.258	0.000	
	Sum CO numbers	0.001869	0.187	0.000258	0.000	1.00
Building Type	Healthcare	0.062	6.396	0.303	0.839	1.81
	Office	-0.145	-13.497	0.305	0.634	1.81
	Residential	0.748	111.277	0.412	0.071	1.38

Table 5 presents the results from the multiple linear regression analysis. The results show that the p-value exceeds the significant level of α = 0.05 for all categorical predictor variables, i.e., none of the building types are statistically significant with relation to $CO/day for the entire dataset. This implies that models of this type need to be constructed individually for each building type, as done in the above analysis. Despite this, interesting conclusions can still be made from the results. For example, the percent increase of the response variable for the sum of change order numbers is about the same magnitude as the individual models above and the variable remains statistically significant with a p-vale of zero. Although none of the categorical predictor variables was statistically significant, they all had variable inflation factor (VIF) values lower than two, suggesting that there is a small chance that the variables are multicollinear.

5. CONCLUSIONS

This paper statistically analyzed the cost and scheduling impacts that change orders have on construction projects across four different building types and summarized the findings as follows:

- Since the average potential cost impact of the sum of change orders for all projects across building types was similar, those with relatively low change order contract amounts stood to face the largest potential cost impacts percentagewise. The percentage lowered as the contract amounts increased; this result held for all building types.
- ANOVA results indicated that the means of the ratio of potential cost impact to potential schedule impact ($CO/day) did not statistically differ among the four building types. The highest mean value was for residential buildings at $13,867,082, while the lowest was for education buildings at $2,293,879. The negative impacts that change orders have on cost and scheduling cannot be overlooked for any type of construction project.
- The sum of current change orders was found to be a statistically significant predictor of $CO/day for all building types except for education. However, linear regression modeling of this kind must be used with caution, as relatively low R^2 values were obtained for individual modeling. The number of change orders had relatively low impact on $CO/day, with an average % increase in the response variable of about 0.2% per the addition of one change order. However, due to the large average number of change orders per project, this impact can be great depending on the project. Multiple linear regression on the entire dataset revealed that building type is not a significant predictor of $CO/day.

With the goals of the paper mostly achieved, it is important to recognize limitations and suggestions on how the work can be improved. The data analyzed did not include information commonly found among other works in the literature, such as project size (square footage), overall project cost, and change order reason, categories, and/or timing. With this information, similar analysis can be conducted for an evaluation.

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