Modeling of Identifying Mediator Effects between Project Delivery Systems and Cost Performance

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Abstract–

This paper addresses the problem of explaining the reason for mixed assessment results in comparing cost performance of project delivery systems (PDS). In particular, we focus on mediator effects for the explanation that would traditionally not be handled by project performance evaluation disciplines. Previous studies revealed that two kinds of disciplines deal with change orders from different points of view. Evaluating PDS by project owners uses change order as a cost performance metric, whereas contractors consider it as a method to increase project cost for their own profit. A Path Analysis model was established by integrating these viewpoints to explain the discrepancy in assessment of PDS. It describes the process how PDS impact on change orders. For the path model, 234 public sector projects completed between 1998 and 2013 in Korea were collected and analyzed. The dataset consists of both Design-Build and Design-Bid-Build projects which are the most prevalent delivery systems. While examining the total effect of PDS on cost performance using the path analysis, mediator effects were significant in building construction project type. This study fills the gap between the successful performance result and the failed adoption of PDS using causal relationship as explanation. The intervention of procurement methods between PDS and their cost performance may provide the clue that project decision makers should consider mediator effects and project characteristics when they select and assess PDS.

Keywords–

Cost Management; Change Order; Cost Performance; Project Delivery System; Design-Build; Design-Bid-Build; Mediator Effect; Path Analysis

1 Introduction

1.1 Background

When project owners decide on a project delivery system (PDS) that will carry out their project within budget, it is important to consider related project and bidding characteristics. From the point of view of the project owner, the cost performance assessment of PDS is as important as the type of PDS used, because an inappropriate selection of PDS based on mistaken assessments may lead to considerable cost overruns and cause confusion throughout the project.

In order to assess PDS, most research compares the two prevalent methods, Design-Build (DB) and Design-Bid-Build (DBB) [1-5]. Research in this area mostly shows that the cost performance of the DB system is regarded as better than the DBB system [1-3, 6]. However, some studies have displayed negative results for the performance of DB against that of DBB depending on project characteristics and different datasets [4, 5, 7, 8]. These inconsistent results could stem from different measurement according to point of view. To measure the cost performance of PDS, various performance metrics such as unit cost, cost growth, intensity (cost/time) are used [1]. The cost growth from contract amount to completion amount is widely used as the cost performance metric. It mostly adopts change order as its operational definition of measurement index by owner's viewpoint [9-12] (Detailed explanation is provided in Section 2.3).

On the other hand, some studies consider change order as a method to preserve or increase contractor's profit during the construction phase [13]. Construction projects where there are significant differences between the selected bid price and the pre-bid estimate of the owner (hereinafter referred to as "bid to estimate ratio") have higher change orders [14-17]. Bid to estimate ratio and change orders are often influenced by the number of bidders depending on PDS in bidding stage [9, 10, 13, 18]. When the number of bidders is large, bid to estimate ratio is lower than a smaller number of bidders due to excessive competition. DB has usually small number of bidders than that of DBB, which can easily increase bid price. That is, DBB has lower bid price than DB, and in case that the bid to estimate ratio of DBB is significant lower than average, the contractors often try to increase change order during construction phase to preserve their profit. These bidding characteristics from contractors' viewpoint, bid to estimate ratio, and the number of bidders affect change orders during the construction phase. Those situations yield that DBB has generally higher change orders than DB. Higher change orders is welcomed by the contractor's viewpoint in those cases. However, from owner's point of view, fewer change order is known as superior in terms of assessment of PDS. From the point of view between owner and contractor, there two types of conflicting studies coexist for the purposes of using change orders.

Consequently, change orders should be understood with two different perspectives between owner and contractor (Figure 1). Owners use change orders to measure project cost performance, while contractors often consider it as a method to increase project cost for their own profit.

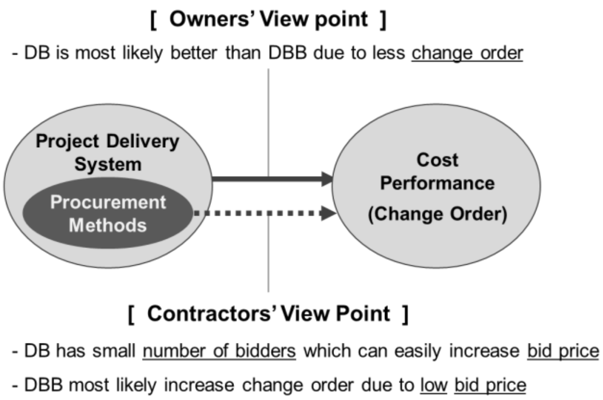

Figure1. Different perspectives between owner and contractor on change order

1.2 Problem Statements

As Figure 1 shows, this issue may lead to debates on cost performance between DB and DBB. Numerous studies have been conducted on each of these topics. However, the methodologies of both studies are limited to correlation or regression models, which can only analyze the dependent relationships of PDS, bid characteristics and change orders, respectively. Because, those methods analyze only direct effects between independent and dependent variables (Figure 2).

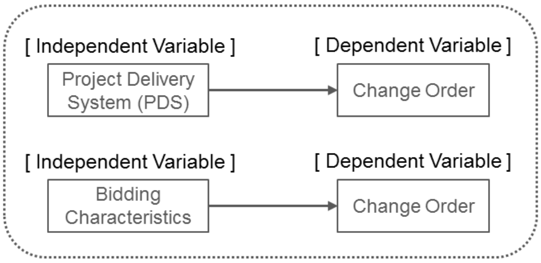

Figure 2. Different viewpoints of studies and their direct relationships

If other factors intervene between independent and dependent variables, they would act as mediator, which means indirect effects occur. Therefore, another method is needed to compare the size of the effects and to identify stronger factors that impact on change orders. To deal with this problem statement, we need to build a single model that combines the different purposes of both the owner's and contractor's viewpoints as influential factors (independent variables). Figure 3 shows the combined model, adopted a Path Analysis method.

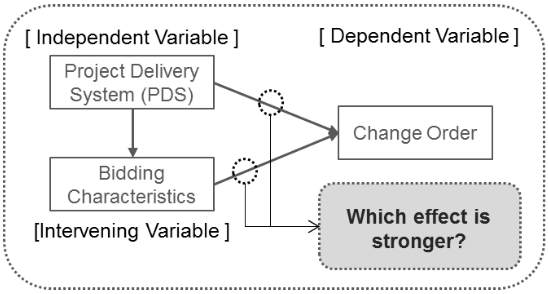

Figure 3. Integrated model of different view points

1.3 Adoption of Path Analysis Method

To deal with the aforementioned problem statements, we adopted a Path Analysis method. It performs causal analysis using a theoretically grounded model and covariance (or correlation) matrix. Compared to system dynamics models, it examines a hypothetical test using empirical data, while system dynamics build a more theoretical model that has difficulty validating the model. Path analysis makes it possible to identify both direct and indirect effects that are otherwise difficult to detect in multiple regression analysis. Path Analysis is a technique that can analyze not only the influence relationship between independent and dependent variables but also the influence relationship between independent variables at the same time [19, 20].

Let us compare path analysis models with multiple regression models. For instance, we can analyze the multiple regression model Y ~ X1 + X2. The regression coefficients are interpreted as how much Y would increase when we increase X1 by 1 and fix X2 at constant value. However, this assumption could be counterfactual if X1 has a causative influence on X2. If X1 increases X2 and X2 increases Y in succession, the regression coefficients of X1 underestimate the causal influence of X1 on Y. Path analysis incorporates the causal influence of X1 on X2 and successfully estimates the causal influence of X1 on Y.

In this paper, the Path Analysis model integrates the factors attributed to the two stakeholders. There is an influential relationship between PDS and bidding characteristics. Both are independent variables that affect change orders in a multiple regression model. The model will identify the relationships and estimate the effect of PDS on cost growth from change orders.

It combines the theory and the data to estimate the causal effects of variables. For the theory, we built a theoretical model through research hypothesis and literature survey, then the path model and real world data were combined and examined.

1.4 Research Objectives and Hypothesis

The objective of this study is to build a Path Analysis model that identifies mediator effects and describe the process of the causal relationship between PDS and cost performance. A database of 234 public sector construction projects completed between 1998~2013 in South Korea was examined for the path model. This study made an effort to explain the cost performance of PDS by illustrating the process of the contractor's impact on change orders by considering the different viewpoints of owners and contractors.

The research hypothesis is that the contractor's intention impacts on change orders that are measured for the cost performance of PDS by owners (Figure 4).

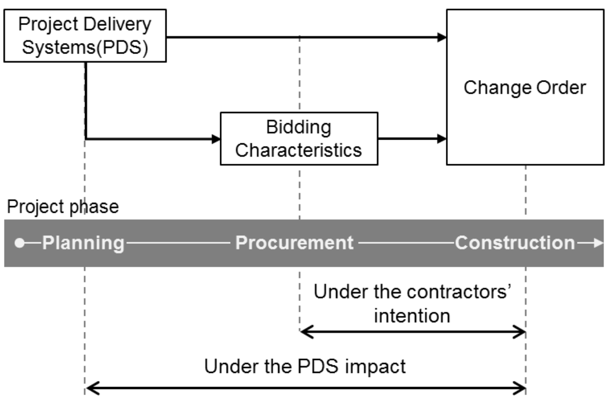

Figure 4. Research hypothesis

The intention will be identified as the mediator effect working between PDS and cost performance.

2 Methods

As described in section 1.3, we built a theoretical model. The data collected was analyzed to establish suitable Path Analysis models and the model that was supported by the data was examined.

2.1 Building a Theoretical Model

Moon [12] studied a mediator effect of bid price to estimate the ratio between PDS and change orders. However, more features can be uncovered and categorized as bidding characteristics that may be part of the contractor's intention. We examined the previous studies on which variables affect the change orders and hypothesized processes regarding how these variables affect the outcome (Figure 5).

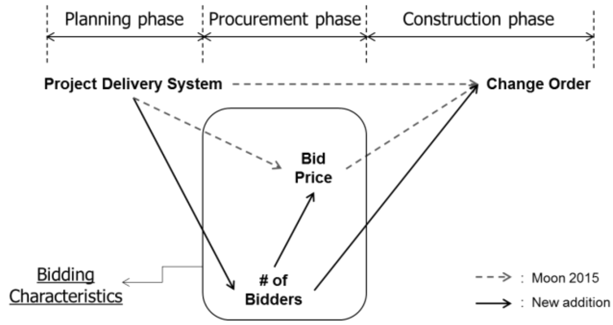

Figure 5. Theoretical path model

2.2 Data Collection and Analysis

This study utilized a database of 234 public sector projects that were completed in South Korea between 1998~2013. Each project awarded by the city of Seoul cost more than five million dollars. Nine project types were constructed and categorized to four types: civil, building, facilities, and landscaping. The sample size of DB and DBB projects are similarly distributed where DB is 97 samples (41.5%) and DBB accounts for 137 samples (58.5%). Figure 6 shows the sample size of each PDS according to project type. Building projects and civil projects were selected for the analysis as each project type has a similar distribution as well as sufficient number of samples for both DB and DBB. In addition, according to reports by the city of Seoul authorities, excessive change orders due to governmental policy and social conditions in four projects were assumed to be outliers and these were removed from the dataset.

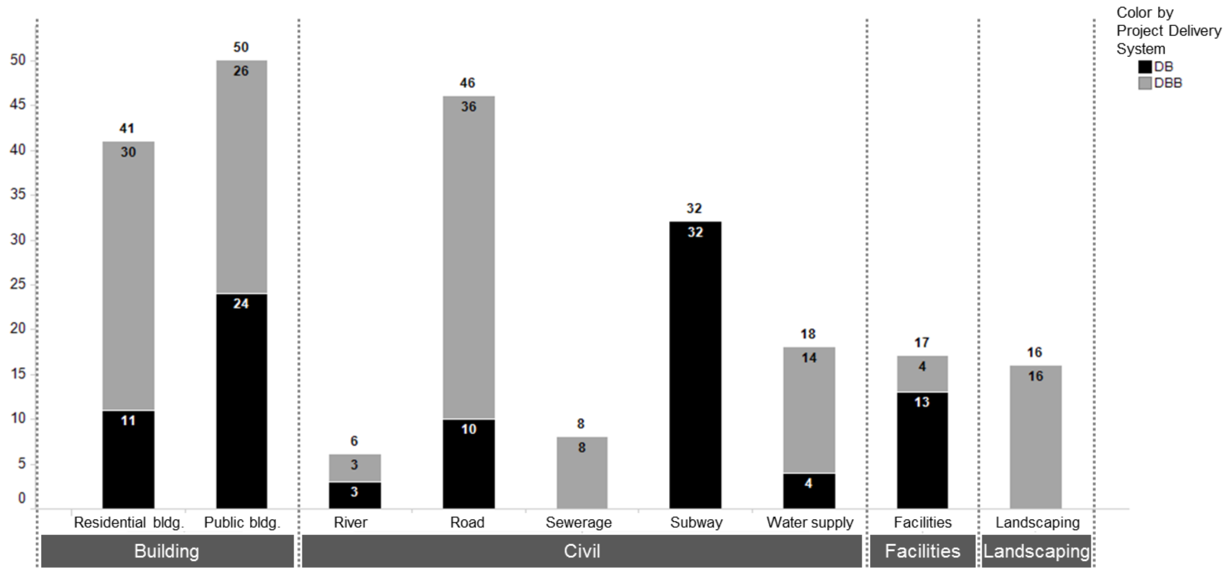

Figure 6. Sample size and project type

2.3 Cost Performance Metric

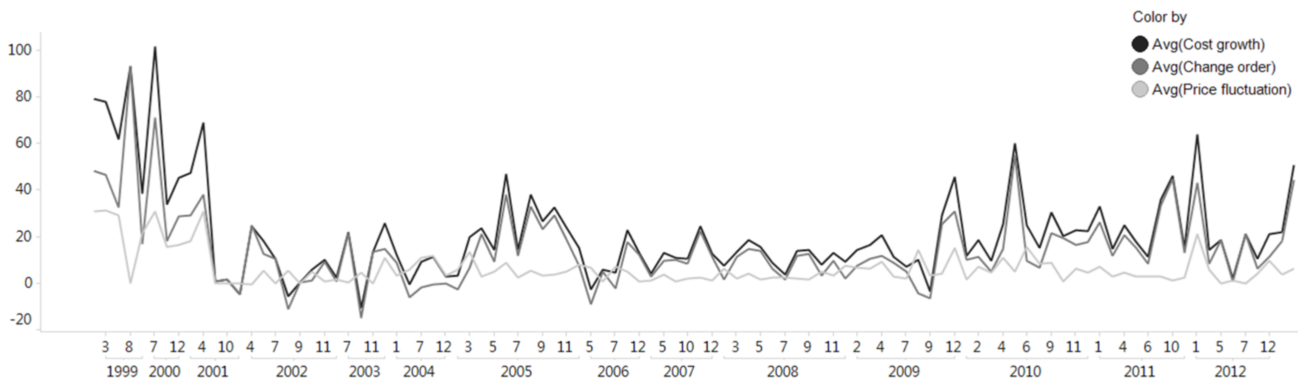

Figure 7. Change order as a cost performance metric

To address cost performance metrics, we analyzed the dataset. A line chart of cost growth rate was projected according to the actual date of project completions. Cost growth rate of the dataset consists of escalation (price fluctuation) and change order rate. Figure 7 shows that both cost growth and change order rates have similar rise and fall curves, but the price fluctuation rate is projected far from the both lines. The cost performance is dominated by change order rather than price fluctuation in the case of the present dataset. Finally, we adopted change order rate as the cost performance metric based on the metrics included in the previous studies [9-12] and data analysis. As operational definition, change order is represented in percentages by comparing the final construction costs which is subtracted fluctuation price to the initial contract cost.

2.4 Path Analysis Model

Unlike independent multiple regressions, path analysis simultaneously estimates the parameters and can estimate the indirect effects (mediator effects) of certain variables. Based on the theoretical model, we postulated the process model of how PDS affects the change order. Figure 8 shows two proposed path models. In the first (Figure 8(a)), PDS has a direct effect on change order and indirect effects through the number of bidders and bid price. In Figure 8(b), PDS has direct and indirect effects on change order, but the indirect effects have different paths. We assumed the number of bidders cannot have direct effects on change order but it has an indirect effect through the bid price. Some studies examined the effect of the number of bidders on change orders [10, 18]. However, we provide statistical evidence that these can be explained via the causal effect model.

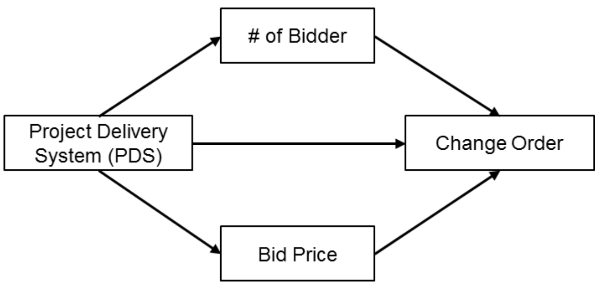

Figure 8(a). The path model-1

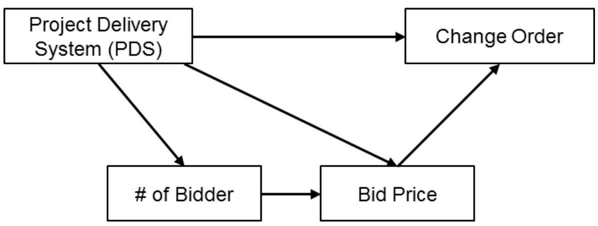

Figure 8(b). The path model-2

We analyzed the data using model described above and used multi-group analysis to incorporate the fact that the process of determining the change order might be different according to project type. We used Full Information Maximum Likelihood (FIML) to utilize the missing data fully. FIML is recommended by several methodologists since it is unbiased even when the missing mechanism is Missing at Random (MAR) rather than Missing Completely at Random (MCAR) [21, 22].

3 Results and Discussion

First of all, we examined the fit of both models to see how probable it is that the proposed models were true. It is advisable to check the fitness of a model before interpreting any coefficients from it [19, 20]. Since the proposed models are only one parameter short of being a saturated model per group, we used the chi-square test to see if the coefficient can be assumed to be 0. The scaled chi-square test [23] of the first model versus the saturated model resulted against the null hypothesis (chi-sq difference (df = 2) 17.56, p-value = 0.0002), meaning that the first model cannot adequately fit to the data. The scaled chi-square test of the second model resulted in a chi-squared difference of 3.4149 with a degree of freedom of 2. P-value was 0.1813 indicating that the second model has adequate fit. Therefore, we used the second model to estimate the effects of PDS.

Since we use multiple group analysis, the first thing to check was whether the coefficients were the same across the groups. We compared the multiple group model with the same coefficients between groups and the model with the different coefficients for each group. We used the chi-square test and the assumption of the same coefficients across groups that could not be justified by the data (chi-square difference = 19.513, df = 5, p-value = 0.002). We also tested if the error variance could be assumed to be the same across the group (allowing the coefficients to be the same for different group) and it was not supported (chi-square difference 46.305, df = 3, p-value = 0.000).

As a result of the aforementioned outcomes, we used models with the different coefficients and different error variance for each group. For powerful analysis, we used bootstrap method to estimate the direct and indirect effects and the standard error of these. We analyzed the data with path model-2.

The fit was adequate with chi-square p-value 0.352, RMSE 0.021(0, 00-0.20), CFI 0.99 and P-value for RMSEA being less than 0.05, 0.439 [24]. Estimated coefficients for building construction projects are in Table 2. In the building construction projects, the direct effect of PDS on change order was not significantly different from 0, but the indirect effect was found to be significant. Table 1 shows the two specific indirect effects of PDS on change order.

Table 1. Effects of PDS on change orders via different paths for building construction projects

Effect	Path	Estimate (Bootstrap confidence interval)	SE	P-value	Standardized
Specific indirect	PDS → # of bidders → bid price → change order	-0.97 (-2.13 ~ -0.12)	0.53	0.067	-0.079
Specific indirect	PDS → bid price → change order	8.65 (1.26 ~ 16.46)	3.94	0.028	0.705
Direct	PDS → change order	-2.91 (-13.93 ~ 6.49)	5.09	0.567	-0.238
Total	Sum of the above	4.76 (-0.86 ~ 10.24)	2.76	0.084	0.388

The results of Table 1 show that both of the specific indirect effects of PDS on change order are significant (Column Estimate shows the estimated coefficients and the .95 confidence interval from bootstrapping. Values in column SE and P-value are results from normal theory). But the sign of the effects is the opposite. Table 1 shows the complicated process of determining change order. Total effect of PDS on change order was insignificant but the indirect effect through the ratio of bid to estimate was significant and the estimate was quite large (8.65 with confidence interval from 1.26 to 16.46).

Table 2 shows all the estimated coefficients from the proposed model for building construction projects. In the results, PDS had significant effects on the number of bidders and bid price. Since the model is causative, we can analyze the causal relationship between variables. For instance, we can figure out what will happen when the number of bidders does not increase for PDS. The first specific indirect effect in Table 1 will be blocked and the effect will disappear so the change order will increase by 0.97 on average.

Table 2. Building construction projects

Antecedent	Consequent								
	M1(# of bidders)			M2(bid price)			Y(change orders)		
	Coefficient	SE	P-value	Coefficient	SE	P-value	Coefficient	SE	P-value
X(PDS)	70.38	13.2	0.00	-15.6	1.55	0.00	-2.91	5.09	0.57
M1(# of bidders)				0.03	0.01	0.00			
M2(bid price)							-0.55	0.26	0.03
Constant	-68.76	13.80	0.00	108.81	2.35	0.00	64.30	29.62	0.03
	R^2 = 0.191			R^2 = 0.562			R^2 = 0.119		

The model appears to be quite reasonable. In particular, the causal chain of PDS on number of bidders, the number of bidders on the ratio of bid to estimate, and the bid to estimate on the change order appears reasonable. As Hume [25] indicated, temporal priority is a necessary condition for causality.

Even though the model showed adequate fit, we could not be sure that the model is true of reality. As

Bollen [26] mentioned, researchers can only say their causal model is consistent with the data in hand and there may be other models that show adequate or better fit. For instance, causal relations can be nonlinear or there might be confounding variables in the causal relationships we hypothesized.

4 Conclusions

Based on previous studies, it is concluded that the DB system outperforms the DBB delivery system due to fewer change orders. This result is from the owner's perspectives in terms of assessment of PDS. However, according to different studies, the number of bidders and bid price during procurement phase also impact on change orders in construction phase. Change orders are often welcomed by contractors to preserve or increase their profit. These two types of research with mixed results were combined and the theoretical model that included PDS, the number of bidders, bid price, and change orders, was developed and tested statistically using Path Analysis method. In a specific project type, the mediator effects of bidding characteristics between PDS and cost performance were validated. In that case, we should not conclude that DB is superior to DBB only due to fewer changes.

This study made an effort to provide a better understanding of the mechanism of PDS impact on cost performance through intervening factors. This research is expected to help project decision makers in selecting a PDS by considering mediator effects of specific projects and bidding characteristics.

More data analysis techniques are needed to gain insight from real world data and for this data to be examined by the Path Analysis method.

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