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UNCERTAINTY ANALYSIS OF PROCUREMENT PHASE PERFORMANCE INDICATORS USING EXTREME BOUNDS ANALYSIS (EBA)

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Abstract: The procurement phase (PP) is one of the major phases of construction projects, which has a significant impact on the ultimate success of projects. Although some studies focused on identifying the PP cost and schedule performance leading indicators, however, the robustness/fragility of these variables have rarely been studied. An analysis of these indicators allow project managers to focus on the primary contributors, and the more robust indicators should receive higher priority when allocating scarce project resources as they are more likely to positively impact project performance. Therefore, the aim of this research is to differentiate between the robust and fragile PP cost overrun and schedule delay indicators. For this reason, this study used the two previously developed regression models, which predict the PP cost and schedule performances. Extreme Bounds Analysis (EBA) was used to study the robustness or fragility of the identified PP indicators. In this study, both Leamer's and Sala-i-Martin EBA methods were used. Since Leamer's method only focuses on the extreme bounds of the indicator's distribution while Sala-i-Martin considers the entire indicator's distribution, the final conclusions were made based on the Sala-i-Martin method. Findings which were presented in both numerical and graphical forms, indicate that "bulk material quality issues", "company's degree of familiarity with technologies to be utilized in the construction phase" and "number of design/engineering organizations" are the three robust PP cost performance indicators. Results of the analysis also reveal that "percentage of design completed prior to the start of construction", "number of execution locations", and "number of supplier organizations" are the robust schedule delay indicators in the PP. The findings of this research will guide project managers in allocating limited human and machinery resources more effectively and efficiently.

1 INTRODUCTION

Construction industry is a critical and important component of each nation's development. Therefore, like any other country, US economic growth highly depends on the planning and execution of the buildings, highways, bridges, and their success. However, the construction industry is dynamic in nature due to uncertainties associated with technologies, budgets, and development processes and the rather complex and uncertain nature of the construction environment challenges project managers in achieving successful construction-project outcomes. Construction projects have different sources of uncertainty originated from shortage of material and labor, unfavorable weather conditions, unstable political environments, inadequate cash reserves, possible inflationary effects on project costs, and the short-term nature of most construction projects. Despite these seemingly endless hurdles, it is nevertheless possible for a project manager to consistently achieve outstanding project results. However, by including project management input based on previous experiences and practices related to success in the execution plan, the likelihood of achieving an outstanding project cost and schedule performance can be enhanced.

One of the major challenges for the practitioners in construction industry is how to define and measure project success. Traditionally, time, cost and quality were considered to be the three main criteria to define project success (De Wit, 1988, Arditi and Gunaydin, 1997; Frimpong et al., 2003; Williams, 2003; Luu et al., 2003). However, Wright (1997) then reduced the number of criteria and suggested only two parameters of time and budget could be the major determinants of a project success level.

Each construction project is composed of three engineering/design, procurement and construction phases. For a construction project to be considered successful, it is expected that this project performs on-time and on-budget in every of the three phases. Construction delays and overruns are often responsible for turning profitable projects into loosing ventures. The major causes of such delays and cost overrun can be identified and dealt with in a timely fashion.

Researchers and practitioners have mainly focused on project performance during the construction phase and some on the engineering phase but rarely the procurement phase has been investigated. Although one may argue that construction phase cost has a major significant impact on ultimate project's performance, but the poor procurement phase performance will also yield a great harm to the execution process of the project. Kermanshachi (2016) has studied and identified nine procurement phase cost and schedule performance indicators for large scale construction projects. However, equal addition of the resources to all nine areas will not necessarily improve procurement phase performance equally. For this reason, this study focuses on uncertainty analysis of all the nine identified procurement indicators to determine resource allocation to which of these areas will definitely improve procurement phase performance. Within the context of this study, identifying robust cost and schedule performance indicators during procurement phase serves to guide project managers in allocating their limited human and machinery resources more effectively and efficiently. In particular, it is recommended that robust indicators receive higher priority when allocating scarce project resources since they are more likely to positively affect project cost and schedule performance.

2 BACKGROUND

According to Abbas (2006), delay is the late completion of a construction project compared to the planned schedule or contract schedule. In short, delay occurs when the progress of a contract falls behind schedule. A delay in contract can have adverse effects on both the owner and the contractor (either in the form of lost revenues or extra expenses) and it often raises the contentious issue of responsibility for the delay, which may result in conflicts and litigation issues. A cost overrun occurs when the final cost of the project exceeds the original estimates (Leavitt et al., 1993; Azhar and Farouqi, 2008). A cost overrun is the increase in the amount of money required to construct a project over and above the original budgeted amount. Datta (2002) described cost escalation as a ubiquitous problem in government projects in India. Anderson et al. (2016) studied best scoping practices to improve on-time and on-budget delivery of highway projects. Some studies have also focused on identification of strategies which reduce potential project cost and schedule overruns (Kermanshachi, 2016 a,b,c).

Many researchers have been attracted to project cost overrun and delay problems. Kaliba et al. (2009) found that the major causes of delays in road construction projects were delayed payments, financial deficiencies of the client or the contractor, contract modifications, economic problems, material procurement issues, changes in design drawings, staffing problems, equipment unavailability, improper or lack of supervision, construction mistakes, poor coordination on the site, changes in specifications, and labor disputes and strikes. El-Razek et al. (2008) found that delayed or slow delivery of payments, coordination problems, and poor communication were important causes of delay in construction projects in Egypt. Sambasivan and Soon (2007) found that poor planning, poor site management, inadequate supervisory skills on the part of the contractor, delayed payments, material shortages, labor supply shortages, equipment unavailability and/or failure, poor communication, and rework were the most important causes of delays in the Malaysian construction industry. Kouskili and Kartan (2004) identified the main factors affecting cost and time overrun as inadequate/inefficient equipment, tools and plants, unreliable sources of materials on the local market, and site accidents. Le-Hoai et al. (2008) identified the top three causes of cost overruns in Vietnam as material cost increases due to inflation, inaccurate quantity takeoffs, and labor cost increases due to environmental restrictions. In their research, Kaliba et al. (2009) concluded that cost escalation of construction projects in Zambia was caused by factors such as adverse weather, scope changes, environmental protection, mitigation costs, schedule delays, strikes, technical challenges, and inflation. Bubshait and Al-Juwait (2002) listed the following as factors that cause cost overruns on construction projects in Saudi Arabia: weather, the number of simultaneous projects, social and cultural impacts, project location, lack of productivity standards, competition level, supplier manipulation, economic instability, inadequate production of raw materials, and absence of construction cost data.

However, few studies have focused on identification of project performance indicators during each of the engineering, procurement and construction phase. Kermanshachi (2016) has investigated and identified main project performance indicators during each of the project development and execution phases. As shown in Tables 1 and 2, Kermanshachi found out that there are nine variables which affect procurement phase cost and schedule performance.

Table 1: Procurement Phase Schedule Performance Indicators

#	Indicators	*P-value*
SI1	Project Engineering Schedule Performance	0.01
SI2	Previous Collaboration Between Designer/Engineer and Contractor	0.01
SI3	Number of Subcontractor Organizations	0.01
SI4	Number of Subcontractor Entities	0.00
SI5	Number of Execution Locations-Procurement Phase	0.01
SI6	Difficulty in System Design and Integration	0.01
SI7	Cost Target at Authorization Compared to Industry Benchmarks	0.04
SI8	Bulk Materials Quality Issues	0.00
SI9	Actual Percentage of Engineering/Design Completion at the Start of Construction	0.00

Table 2: Procurement Phase Cost Performance Indicators

#	Indicator	*P-value*
CI1	Use of Quality Management Strategy	0.00
CI2	Total Engineering Phase Change Orders	0.02
CI3	Project Management Team Experience -Procurement Phase	0.01
CI4	Project Engineering Cost Performance	0.00
CI5	Number of Permitting Agency Organizations	0.00
CI6	Number of Financial Approval Authority Thresholds	0.03
CI7	Number of Designer/Engineer Organizations	0.00
CI8	Company’s Familiarity with Technologies Involved in Construction phase	0.00
CI9	Bulk Materials Quality Issues	0.03

3 RESEARCH METHODOLOGY

The goal of EBA is to find out which independent variables (selected from a set of X) are robustly associated with the dependent variable y. A great deal of literature exists which contain detailed and rigorous description of EBA. Examples include Leamer (1985), Sala-i-Martin (1997), Hendry and Krolzig (2004), and Angrist and Pischke (2010).

The process starts with running a large number of regression models, each containing y as the dependent variable, and including a set of standard explanatory variables F that are included in each regression model. In addition, each model includes a different subset D of the variables in X. The subset D whose regression coefficients are statistically significant in a large enough proportion of estimated models are denoted as robust, whereas those that do not are referred to as fragile. In order to determine if a variable v ∈ X is robustly correlated with the dependent variable y, a set of regression models is estimated as follows,

$$y = \alpha j + \beta j v + \gamma j F + \delta j Dj + \varepsilon$$

In the EBA formulation, the regressions were estimated by Ordinary Least Squares (OLS). In recent research, however, other types of regression models have also been implemented. Examples include ordered probit models (Bjørnskov et al., 2008), and logistic models (Gassebner et al., 2013). The final model output is more susceptible to slight changes in the input of a fragile variable. On the contrary, changes in the input of a robust variable do not significantly affect the model output.

3.1 Leamer's EBA

In order to decide whether a variable is robust or fragile, Leamer's EBA focuses only on the extreme bounds of the regression coefficients (Leamer 1985). In particular, for any variable v, the lower and upper extreme bounds are defined as the minimum and maximum values of $\hat{\beta}_j + \tau.\hat{\sigma}_j$ across the M estimated regression models, where τ is the critical value for the desired confidence level. For example, for 95 percent confidence level, a τ value of 1.96 is used. If the upper and lower extreme bounds have the same sign, variable v is declared robust, and if the opposite is true, it is referred to as fragile. The interval between the lower and upper extreme bounds represents the set of values that are not statistically significantly distinguishable from the coefficient estimate $\hat{\beta}_j$. In other words, a simple t-test would fail to reject the null hypothesis that the true parameter βj equals any value between the extreme bounds. Intuitively, Leamer's version of EBA scans a large number of model specifications for the lowest and highest value that the βj parameter could take at the desired confidence level. It then labels variables as robust or fragile based on whether these extreme bounds have the same or opposite signs, respectively. Perceivably, Leamer's EBA relies on a very demanding robustness criterion, since the results from a single regression model are enough to classify a variable as fragile. Figure 1 shows that the Leamer's EBA null hypothesis is set at zero. If the distribution curve of regression coefficients does not pass the null hypothesis value (i.e. zero), the variable is marked as robust. Also, following this Figure, a variable is declared fragile even if the extreme bounds have the same sign in all but one of the estimated models. According to Sala-i-Martin (1997), "if the distribution of [regression coefficients] has some positive and some negative support, then one is bound to find one regression for which the estimated coefficient changes signs if enough regressions are run." Therefore, it is no surprise that studies that have used Leamer's EBA to test the robustness of variables have generally labeled most (if not all) as fragile (Sala-i-Martin 1997).

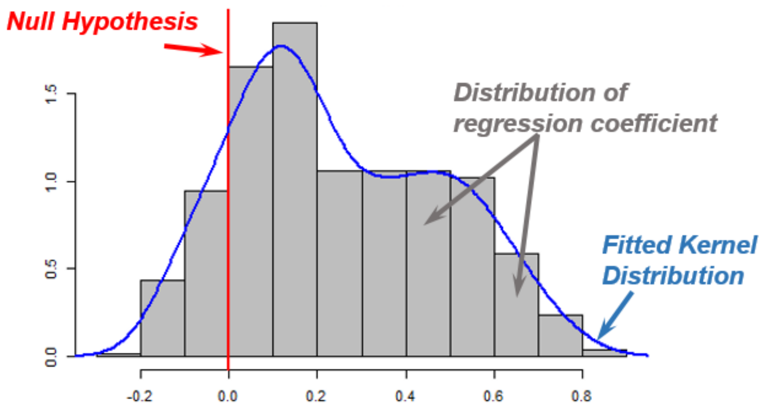


Figure 1. Illustration of EBA null hypothesis, distribution of regression coefficients, and fitted distribution

3.2 Sala-i-Martin's EBA

To alleviate some of the drawbacks of the Leamer's EBA, Sala-i-Martin (1997) proposed an alternative EBA method that essentially focuses on the entire distribution of regression coefficients, instead of only its extreme bounds. Rather than applying a binary label of robust or fragile, this method assigns some level of confidence to the robustness of each of the variables. In particular, Sala-i-Martin (1997) considers the value of *CDF*(0), the fraction of the variable's cumulative distribution on each side of zero. According to the literature on Sala-i-Martin, "if 95 percent of the density function for the estimates of β_1 lies to the right of zero and only 52 percent of the density function for β_2 lies to the right of zero, one will probably think of variable 1 as being more likely to be correlated with [the dependent variable] than variable 2." In short, Sala-i-Martin's EBA considers a variable more robust if a greater proportion of its coefficient estimates lies on the same side of zero. It is understood that although the coefficients in each individual model have an asymptotic normal distribution, the coefficient estimates obtained from different regression models might be scattered less predictably and may not follow any particular distribution. For this reason, Sala-i-Martin (1997) presents two variants of his EBA: (1) a normal model, in which the estimated regression coefficients are assumed to follow a normal distribution across the estimated models, and a (2) generic model, which does not assume any particular distribution of regression coefficients.

4 DATA ANALYSIS AND RESULTS

4.1 Sensitivity Analysis of Procurement Phase Schedule Performance Indicators

Table 3 shows the results of the sensitivity analysis on schedule performance determinants during the procurement phase. As the results revealed, eight out of nine independent schedule performance variables during the procurement phase are robust and there is only one fragile indicator. Based on the analysis, project engineering schedule performance (SI1) will be an indicator of the project schedule overrun during the procurement phase. This problem happens when uncertainties in the design phase impose the proper planning in the procurement phase. The other robust procurement phase schedule overrun is the number of supplier organizations (SI3). This study indicated that if the number of suppliers to the project increases, there will be less schedule overrun. The reason for this relationship is that if more supplier organizations are involved, unavailability of a certain type of material will not affect the project, as that material will be provided by other suppliers. The same study also concluded that if the number of subcontractors involved in the project (SI4) increases, there would be less procurement phase schedule overrun due to an increase in the number of skilled workers and the possibility of breaking the work down to smaller specialty tasks.

Table 3. Extreme Bound Analysis of Procurement Phase Schedule Performance Indicators

Indicator	Leamer EBA test		Sala-i-Martin EBA				Robustness
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	
SI1	-0.41	0.07	99.10	0.90	97.54	2.46	Robust
SI2	-0.01	0.02	8.16	91.84	11.88	88.12	Fragile
SI3	-0.40	0.18	95.75	4.25	89.36	10.64	Robust
SI4	-0.27	0.05	97.58	2.42	96.77	3.23	Robust
SI5	0.00	0.02	0.05	99.95	0.13	99.87	Robust
SI6	-0.01	0.10	0.44	99.56	0.99	99.01	Robust
SI7	-0.01	0.10	2.18	97.83	2.54	97.46	Robust
SI8	0.01	0.13	0.04	99.96	0.14	99.86	Robust
SI9	-0.01	0.00	99.87	0.13	99.39	0.61	Robust

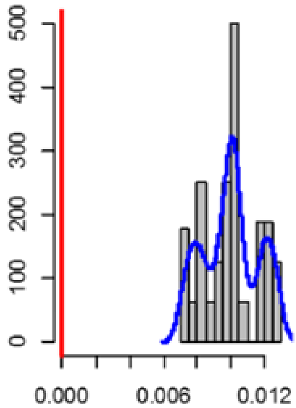
(SI1): Project Engineering Schedule Performance, (SI2): Previous Collaboration Between Designer/Engineer and Contractor, (SI3): Number of Supplier Organizations, (SI4): Number of Subcontractor Entities, (SI5): Number of Execution Locations-Procurement Phase, (SI6): Difficulty in System Design and Integration, (SI7): Cost Target at Authorization Compared to Industry Benchmarks, (SI8): Bulk Materials Quality Issues, (SI9): Actual Percentage of Engineering/Design Completion at the Start of Construction.

The outcome of the EBA in Table 3 shows that if there are multiple execution locations for a single project (SI5), there is a probability that the project schedule during the procurement phase will suffer. In such projects, program managers should have a detailed plan for distributing human and equipment resources across multiple locations. Difficulty in system design and integration (SI6) is another robust procurement phase schedule performance indicator. System is the combination of several pieces of equipment to perform in a particular manner. If compared to other typical projects, there is a difficulty in system design and integration of the project, the procurement phase schedule could face an overrun.

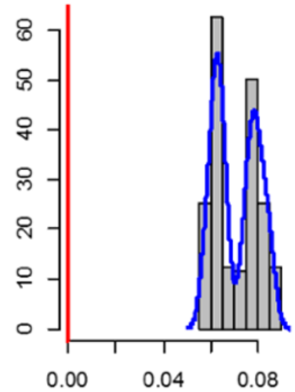
Table 3 shows that if at the time of authorization, the project cost target is higher compared to the industry targets (SI7), the project has a high probability of facing schedule overrun in the procurement phase. This issue could be explained due to the complexity and difficulty of arranging the required resources for the larger scales projects. Bulk material quality issues (SI8) is another robust procurement phase schedule overrun. Any material quality problem will slow down the execution process since those materials should be returned to the supplier and the new materials should be provided and delivered by the same supplier, or a new supplying organization should be found. The last robust procurement phase schedule performance indicator is the percentage of design completion prior to the construction (SI9). As the analysis shows, if the design is more complete before construction starts, there will be less uncertainties associated with the project and thus, there is a low chance of schedule overrun in the procurement phase.

The only fragile procurement schedule performance determinant is the previous collaboration between the designer and the contractor (SI2). The relationship shows that previous collaboration between these two entities may reduce the possibility of procurement phase schedule overrun. This event could be explained due to their familiarity with each other’s processes as well as less potential for disagreement and conflicts. However, if the repetition of the collaboration is due to mandatory regulations and the designer and contactor must work together despite of their unsuccessful experiences, procurement phase may face some unexpected delays.

Figure 2 illustrates the normality or non-normality of coefficient distributions for two procurement phase cost overrun indicators. As shown in this Figure, both SI5 and SI8 are robust procurement phase schedule indicators. Increase in number of execution locations during procurement phase as well as quality issues in bulk materials will make the project phase delays unless proactive strategies are applied.



A: SI5-Number of Execution Locations-Procurement Phase



B: SI8-Bulk Materials Quality Issues

Figure 2. Graphical representation of Sala-i-Martin EBA for Two Robust PP Schedule Performance

4.2 Sensitivity Analysis of Procurement Phase Cost Performance Indicators

Table 4 shows the results of sensitivity analysis of the procurement cost performance predictive model determinants. The analysis shows that if the number of permitting agencies increases (CI5), the procurement phase cost performance is likely to suffer. The same results also show that if there is a greater number of designer/engineer organizations involved in the project (CI7), the project will face less cost overrun during the procurement phase. This could be due to the availability of more diverse and skilled human resources. In this case, the designers would plan and select the project materials and logistics in a more optimized manner. Company's familiarity with technologies involved in the construction phase (CI8) is another robust procurement phase cost performance indicator. According to this study, if the project utilizes technologies which have been successfully tested and used before, the procurement phase will face less cost overrun due to the presence of sufficient past information about the potential technologies and/or equipment to be purchased or used in the project.

Table 4. Extreme Bound Analysis of Procurement Phase Cost Performance Indicators

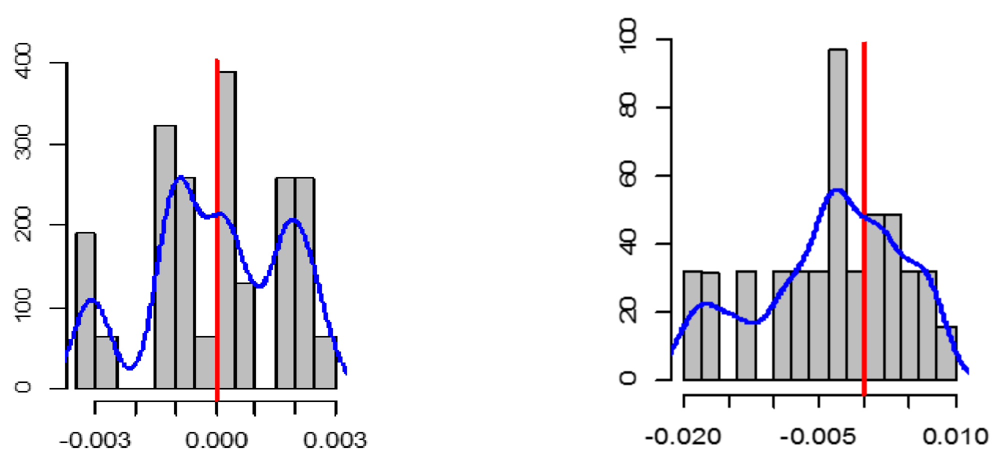
Indicator	Leamer EBA test		Sala-i-Martin EBA				Robustness
	Lower Extreme Bound	Upper Extreme Bound	Normal CDF(β<=0)	Normal CDF(β>0)	Non-Normal CDF(β<=0)	Non-Normal CDF(β>0)	
CI1	-0.18	0.04	94.56	5.45	92.85	7.15	Fragile
CI2	-0.01	0.01	49.85	50.15	51.60	48.40	Fragile
CI3	-0.05	0.03	63.33	36.68	61.02	38.98	Fragile
CI4	-0.03	0.05	14.66	85.34	17.46	82.54	Fragile
CI5	0.00	0.00	2.57	97.43	2.61	97.39	Robust
CI6	-0.01	0.21	9.24	90.76	9.45	90.55	Fragile
CI7	-0.01	-0.01	100.00	0.00	100.00	0.00	Robust
CI8	-0.09	0.02	98.77	1.23	97.55	2.45	Robust
CI9	-0.02	0.08	0.78	99.22	3.24	96.76	Robust

(CI1): Use of Quality Management Strategy, (CI2): Total Engineering Phase Change Orders, (CI3): Project Management Team Experience-Procurement Phase, (CI4): Project Engineering Cost Performance, (CI5): Number of Permitting Agency Organizations, (CI6): Number of Financial Approval Authority Thresholds, (CI7): Number of Designer/Engineer Organizations, (CI8): Company's Familiarity with Technologies Involved in Construction phase, (CI9): Bulk Materials Quality Issues.

The same study shows that bulk materials quality issues (CI9) is another robust determinant of procurement phase cost performance. This sensitivity analysis explains that if there are quality issues with bulk materials, the project encounters procurement phase cost overrun due to the extra time spent on exchanging faulty fabricated materials.

This study concluded that there are also some fragile variables which could predict the procurement phase cost performance. As Table 4 shows, implementing a quality management strategy (CI1) may improve project cost performance during the procurement phase. Quality management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and startup elements of construction projects. Engineering phase change orders (CI2) is the other determinant of procurement phase cost overrun. Results show that if the value of change orders during the engineering phase increases, there will be a negative impact on procurement phase cost performance. The reason behind this undesirable influence is that change orders issued by the owner may require some adjustments in the delivery of materials and equipment. Project engineering cost performance (CI4) is also an indicator of procurement phase cost overrun. Based on the EBA results, if a project has poor performance during the engineering phase, there is a high chance of cost overrun in the procurement phase as well. PMT experience during the procurement phase (CI3) is the last fragile cost performance predictive model indicator which could impact cost overrun. PMT experience could help to better plan and manage procurement phase activities which in turn, reduces the possibility of cost overrun in this phase. However, experienced PMT members may be hesitant to try new and innovative methods of managing procurement activities in case any unexpected event happens during this phase. Therefore, depending on different project parameters, PMT experience could have favorable or unfavorable impact on procurement phase cost performance.

Figure 3 illustrates the normality or non-normality of coefficient distributions for procurement schedule overrun indicators. As shown in this Figure, both (CI3) and (CI6) are fragile variables which means that increasing PMT experience and increase in number of financial approval authorities may positively or negatively impact procurement phase cost performance.



A: CI3-Project Management Team Experience -Procurement Phase

B: CI 6-Number of Financial Approval Authority Thresholds

Figure 3. Graphical representation of Sala-i-Martin EBA for Two Fragile PP Cost Performance

5 CONCLUSION

The overarching goal of this study was to determine how robustly each of the cost and schedule indicators are associated with the procurement phase performance. This study concluded that procurement phase cost performance has more fragile indicators compared to the schedule indicators. In other words, the contractors should pay more attention to the resource allocation when it is intended to optimize procurement phase cost performance. Analysis indicated that adding resources to five fragile cost indicators might not necessarily improve the ultimate phase cost performance. However, procurement phase schedule performance has more robust indicators and focus on each of these indicators will prevent potential project delays. This study also found out that bulk material quality issues will negatively impact both procurement cost and schedule performance and if there is a possibility that the vendor may not provide quality materials, it is suggested to supply materials from trusted resources even if costs more.

This research contributes to the field of construction engineering and management by determining the robustness of each of the procurement phase cost and schedule performance indicators, which assists project managers to allocate their resources more effectively. Identifying and understanding phase-based cost and schedule indicators could potentially benefit high level managers of contracting companies in the decision making process regarding how to proceed with a specific project execution strategy. These results could also help the owners to have a more realistic view of the time and cost associated to the process of project development.

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