Resource-Based Exploratory Analysis of Project Complexity Impact on Phase-Based Cost Performance Behavior

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ABSTRACT

In the field of construction engineering, practitioners frequently encounter uncertainties in the process of decision-making and management of complex projects. These uncertainties associated with project complexity, which vastly affect the project development and execution process, may cause favorable/unfavorable impacts on projects cost performance. Several scholars believe that project complexity may cause unintended consequences on project performance; however, some other researchers stated that complex projects might receive higher attention and more resources and as a result, may face less cost overruns. Therefore, this study initially aims investigate the impact of complexity on phase-based cost performance. For this reason, forty-four case studies consisting thirty high complexity projects and fourteen low complexity ones were collected. Then, Engineering, Procurement and Construction (EPC) phase cost performance of high and low complexity projects were studied and compared. To analyze the collected data, Two-sample t-test was utilized. Analysis indicated that complex projects have better EPC phase cost performance compared to low complexity ones. Finally, to find out the underlying causes of better cost performance of high complexity projects in comparison with low complexity ones, the allocated resources and implemented Best Practices (BPs) were studied. It was observed that high-level of constructability, alignment, partnering, front-end planning, team building, and change management best practices were implemented in complex projects. The findings of this study can help project/program managers (PM) to better understand the phase-based behavior of cost performance in complex projects, and hence implement strategies and allocate resources effectively and efficiently in complex projects.

INTRODUCTION

Construction industry is inherently uncertain and complex due to the nature of industry itself. Practitioners and researchers have many challenges while facing uncertainties and complexity throughout construction projects. Scholars believe that with a proactive complexity management plan, a construction project may face less frequent and/or severe uncertainties. For many years, researchers did not agree on a single widely accepted definition of project complexity (Edmonds, 1999, Sinha et al. 2001). To address this issue, Dao et al. (2016) performed a comprehensive analysis on complexity and its impact on project. The same researchers (Dao et al., 2017) defined project complexity as “the degree of differentiation of project elements,
interrelatedness between project elements, and consequential impact on project decisions”. As part of this research project, 34 complexity indicators were identified and categorized. The 11 identified complexity categories are as following: stakeholder management, governance, legal, fiscal planning, interfaces, scope definition, location, design and technology, project resources, quality management and execution target.

One major challenge that scholars and practitioners frequently face is the accurate estimation of the ultimate cost performance in complex projects. In 2004, Chen et al. stated that if the project complexity is not properly managed, it is very probable that significant project cost overruns occur during the construction phase. Moreover, Sheard and Mostashari (2009) demonstrated that in complex construction projects, it is not possible to predict accurately the cost behavior of construction projects, as each project consists large number of constituent parts within the system and there are several dense relationships among these parts. Several researchers have demonstrated that if project complexity increased in a project, the cost performance would be adversely affected (Lue et al., 2016, Abdou et al. 2016). On the contrary, Kennedy et al. (2011) stated that increasing complexity could have positive impact on the communication-performance relationship, which contributes to the project performance and success. In addition, Floricel et al. (2015) found and documented several complexity, uncertainty-reduction strategies, which have favorable impact on project performance. Although both desirable and undesirable impacts of complexity on project cost performance have been studied before, however, the underlying reasons for such behavior have rarely been investigated and explored.

The overall goal of the study presented in this paper was to investigate the impact of complexity on cost performance in three EPC phases of construction projects. This aim was obtained by the following objectives: (1) analyze the cost performance differences between high and low complexity projects, (2) identify the impact of complexity indicators on phase-based cost performance of complex projects, and (3) investigate the potential reasons and resource allocation strategies which led to the observed differences. The outcomes of this study adds a substantial value to the current complexity and cost performance body of knowledge and helps practitioners and PMs to manage cost performance of complex projects more effectively.

LITERATURE REVIEW

Historically, complexity had a vague meaning, and there was not a standard definition for this terminology. In this respect, the researchers had issue to quantify precisely complexity in construction projects (Corning 1998). Complex projects are complicated in their nature (Chan et al. 2004). Baccarinni (1996) considered complexity as an intrinsic property of a system, a concept that incited researchers to measure complexity. In addition, the author regarded complexity as technological complexity and organizational complexity. In 1999, Williams described complexity as structural complexity. Dao et al. (2017) in their studies mentioned that complexity is often used interchangeably with two concepts: project difficulty and project risk. Complex projects concentrate on obstacles that make achieving the objectives of the project difficult. In addition, project complexity focuses on uncertainties related to unknowns and unpredictable actions (Kermanshachi et al., 2016). Cicmil et al. (2006) highlighted that the complexity is significantly involved in project management. Therefore, complexity has been defined as one of the most fundamental characteristics of construction projects. Consequently, several scholars have tried to quantify complexity in projects by measurement factors and categorization (Gransberg et al. 2013, He et al. 2015, Kermanshachi et al. 2016a and 2016b). Moreover, many studies have been conducted to investigate the impact of complexity on project performance. Bosch-Rekvet (2011) concluded that in large-scale projects, Complexity has negative impact on project performance.
because of complicated technical and organizational project complexity. Puddicombe (2011) explained, after analyzing more than 1300 projects, that novelty and technology as two important project characteristics have distinct effects on project performance. On the contrary, as mentioned earlier, with implementing complexity, uncertainty-reduction strategies enhancing project performance would be achievable.

To improve project’s performance, many resources and strategies have been introduced to practitioners and scholars. In this respect, CII has introduced fourteen strategies, which are called Best Practices (BPs). CII explained BP as “a process or method that leads to enhanced project performance, when executed effectively”. Implementation and adoption of proper BPs could significantly help in the management of large-scale projects. Although implementing all CII BPs could be beneficial for construction complex projects, it may not be practicable. Safapour et al. (2017) provided a decision-making guideline with the selection and implementation process of five CII BPs (Team Building, Alignment, Change Management, Front End Planning and Partnering) which lead to the major cost saving and schedule reduction for the owner entities.

RESEARCH METHODOLOGY

To meet the objectives of this study, a six-step research approach was developed. As it is illustrated in Figure 1, the first task was to review the existing literature to determine the potential impact of complexity on phase-based cost performance of construction projects. The research objectives and questions were then defined to direct the research around the focus point. In the second task, forty-four case studies and their information regarding to project budget and actual cost, complexity, and other physical and managerial characteristics were collected (thirty high complexity projects and fourteen low complexity were gathered). In addition, the implementation level of the thirteen construction BPs (Constructability, Team Building, Alignment, Partnering, Front End Planning, Change Management, Risk Assessment, Material Management, Planning for Start-up, Safety, Dispute Prevention, Quality Management, and Lessons Learned) were also requested and documented. Qualitative data analysis was then used to study the phase-based differences of baseline budget and cost performance between low and high complexity projects.

Figure 1. Research Methodology Process

Next, quantitative statistical analysis such as Two-sample t-test was utilized to answer the following research questions:

*Research Question 1:* Is there a statistical significant difference between the phase-based cost performances of high and low complexity projects?
Null Hypothesis (H0) – The phase-based differences of cost performance between high complexity projects and low complexity ones are not significant. In other words, the complexity has no impact on phase-based baseline budget and cost performance.

Alternative Hypothesis (H1) – The phase-based differences of cost performance between high complexity projects and low complexity ones are significant. In other words, the complexity has impact on phase-based baseline budget and cost performance.

Research Question 2: Which of the 34 complexity indicators have significant impact on cost performance of all the three EPC phases?

Research Question 3: Is there a significant difference between the BP implementation level of high and low complexity projects? At the end, the results were interpreted and discussed.

DATA ANALYSIS AND RESEARCH RESULTS

Preliminary Data Analysis

Among forty-four collected case studies, thirty of them belonged to heavy industrial projects, and the rest belonged to the buildings, light industrial facilities, and infrastructure projects. The average actual cost was $284 million; with minimum value of $0.4 million and maximum value of $5.6 billion. Furthermore, the average duration of projects was 28 months, with minimum of 8 months and maximum of 70 months. Concerning delivery method selection, 34% of the collected projects adopted Design-Build delivery method, 32% selected Design-Bid-Build, 25% utilized Multiple-Primes, and 8% proceed with Construction Management at Risk. In terms of the contract type selection, 48% of the projects were executed with lump sum contract type, and the remained were proceeded with cost reimbursable contract type.

Statistical Data Analysis

In the first place, to investigate the impact of complexity on phase-based cost performance of construction projects, the baseline budget of thirty high complexity projects was compared with fourteen low complexity ones in three design, procurement and construction phases. As illustrated in Figure 2a, the average baseline budget in high complexity projects is substantially higher than low complexity ones in all the three EPC phases. Total project cost, shown in Figure 2, represents the summation of the costs of all three EPC phases.

The maximum average actual cost differences between high and low complexity projects were $196.5 in procurement phase. In addition, there was $247 million difference between the total average baseline budget of high complexity projects and low complexity ones. In Figure 2b, the monetary value of phase-based actual cost deviations from their initial budgeted estimates were plotted. As shown in this Figure, the average dollar value of cost deviations in high complexity projects were significantly higher than low complexity ones. The maximum differences of average cost difference were $19.1 million in procurement phase.

As shown in Figure 3, box plots were used to demonstrate the phase-based cost performance differences of high and low complexity projects. The results revealed that complex projects demonstrated substantial better percentagewise cost performance compared to the low complexity ones. It was observed that the median cost performance of design/engineering phase in high complexity projects had 6.5% less deviation from their initial estimates compared to the low complexity ones. The same analysis for the construction phase cost performance indicated that high complexity projects had 33.5% less deviation compared to the low complexity ones. However, as opposed to the engineering and construction phase cost performances, procurement
phase analysis of high complexity projects demonstrated 4% more deviation in their medians from their initial estimated budgets. Total cost performance which is the summation of cost performance of all the three phases presented 5% better cost performance in the median of high complexity projects. It is very important to mention that because the phase-based initial budget of high complexity projects is considerably higher than low complexity ones, as shown in Figure 2, a few percent of cost performance difference in high complexity projects means great difference in terms of the dollar values.

Figure 2. Comparison of average baseline budget, and average cost performance between low and high complexity projects

To find out if the differences between the cost performances of high and low complexity projects were statistically significant, Two-sample t-test was utilized. As shown in Table 1, the phase-based baseline budget and cost performance difference of high and low complexity projects were significantly different. As it is presented in the same Table, this study initially conducted the statistical analysis at the 0.05 significance level and then raised to 0.1. In this analysis, the significance of phase-based baseline budget and cost performance difference of low and high complexity projects was statistically tested. The outcome of the analysis revealed that the cost performance of design/engineering and construction phases in high complexity projects was significantly better than low complexity ones. On the contrary, the cost performance of low complexity projects in procurement phase was significantly better than high complexity ones.

Table 1. Budget and Cost Performance Significance Test Results for Low and High Complexity Projects

<table>
<thead>
<tr>
<th></th>
<th>Engineering/Design</th>
<th>Procurement</th>
<th>Construction</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Budget</td>
<td>0.095*</td>
<td>0.085*</td>
<td>0.095*</td>
<td>0.045**</td>
</tr>
<tr>
<td>Cost Performance</td>
<td>0.004**</td>
<td>0.012**</td>
<td>0.023**</td>
<td>0.098*</td>
</tr>
</tbody>
</table>

** denotes significant differences with 95% confidence; * denotes significant differences with 90% confidence

Next, the impact of complexity indicators on phase-based cost performance of high complexity projects was studied. As the type of data was continuous, Two-sample t-test was utilized for statistical analysis. It is important to note that the abbreviation of CI (Complexity Indicator) and the following numbers (e.g. CI-7) in Table 2 is the same as original ones in research of Dao et al. (2017).
As the results are shown in Table 2, with an increasing number of joint venture partners in a project, the number of stakeholders and managers who have authority for decision-making during each phase of a construction project would increase. Therefore, it might lead to chaos that could have serious effects on cost performance.

In addition, increasing the number of funding phases/gates leads to delays in funding that cause work authorization problems. Moreover, increasing the number of funding phases is supposed to cause delays in starting each phase and accordingly affecting the cost performance of every phase. Inherently, more required number of permits or existing difficulty in obtaining permits and/or approvals, would increase rework and schedule timing that directly leads to reduction in cost performance (Kermanshachi et al. 2017). Furthermore, one of the reasons that the target of project funding and/or scheduling is substantially different with the industry benchmark might be complicated scope and design. In this situation, skilled and experienced staff for design, procurement and construction phases are required (Kermanshachi et al. 2017).

To investigate if complex projects adopted and/or utilized different types of resources and strategies leading to relative better cost performance, the implementation level of the CII Best Practices was tested. As stated earlier, CII (IR-166-3) introduced BPs to improve performance of construction projects. For this purpose, the frequency of implementation level of thirteen BPs (Constructability, Team Building, Alignment, Partnering, Front End Planning, Change Management, Risk Assessment, Material Management, Planning for Start-up, Safety, Dispute Prevention, Quality Management and Lesson Learned) was statistically tested to observe the significant differences between the implementation level of BPs in both high and low complexity projects.

Two-sample t-test was utilized to analyze the frequency of implementation level of BPs in differentiating high and low complexity projects, resulting in P-Value of 0.07. The result demonstrated that the frequency of the implementation level of BPs in high complexity projects was significantly higher than low complexity ones. To analyze in detail, the difference of high and low complexity projects based on the implementation level of CII BPs was investigated. As the results are shown in Table 3, Constructability, Team Building, Alignment, Partnering, Front End Planning, Change Management, Risk Assessment, Material Management, Planning for Start-up, Safety, Dispute Prevention, Quality Management and Lesson Learned
Planning and Change Management were significantly implemented in high complexity projects compared to low complexity ones.

Table 2. The Impacts of Complexity Indicators on Phase-Based Cost Performance

<table>
<thead>
<tr>
<th>Categories</th>
<th>Complexity Indicators</th>
<th>Design</th>
<th>Procurement</th>
<th>Construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governance</td>
<td>CI-4- Total number of joint-venture partners in this project.</td>
<td>0.098*</td>
<td>0.065*</td>
<td>0.068*</td>
</tr>
<tr>
<td></td>
<td>CI-6- Number of times on this project that a change order will go above the Project Manager for approval.</td>
<td>0.04**</td>
<td>0.066*</td>
<td>0.089*</td>
</tr>
<tr>
<td>Fiscal Planning</td>
<td>CI-7- Number of funding phases (gates) from concept to project completion.</td>
<td>0.001**</td>
<td>0.033**</td>
<td>0.027**</td>
</tr>
<tr>
<td></td>
<td>CI-8- Specific delays or difficulties in securing project funding.</td>
<td>0.001**</td>
<td>0.048**</td>
<td>0.042**</td>
</tr>
<tr>
<td>Legal</td>
<td>CI-10- Number of total permits to be required.</td>
<td>0.001**</td>
<td>0.006**</td>
<td>0.03**</td>
</tr>
<tr>
<td></td>
<td>CI-11- Level of difficulty in obtaining permits.</td>
<td>0.001**</td>
<td>0.009**</td>
<td>0.027**</td>
</tr>
<tr>
<td></td>
<td>CI-12- Difficulty in obtaining design approval.</td>
<td>0.001**</td>
<td>0.041**</td>
<td>0.006**</td>
</tr>
<tr>
<td>Execution target</td>
<td>CI-16- Compare target project funding against industry/internal benchmarks.</td>
<td>0.001**</td>
<td>0.073**</td>
<td>0.007**</td>
</tr>
<tr>
<td></td>
<td>CI-17- Compare target project schedule against industry/internal benchmarks.</td>
<td>0.001**</td>
<td>0.013**</td>
<td>0.027**</td>
</tr>
</tbody>
</table>

** denotes significant differences with 95% confidence; * denotes significant differences with 90% confidence

As shown in Figure 4, the implementation level of the significant BPs adopted in the 44 projects as case studies with regard to their complexity levels were calculated and plotted. The implementation level of Partnering in high complexity projects was approximately 30% higher than low complexity ones. In addition, the implementation levels of Constructability and Front End Planning in high complexity projects were roughly 25% more than low complexity ones.

Table 3. P-Values of BPs Implementation between High and Low Complexity Projects

<table>
<thead>
<tr>
<th>Best Practices</th>
<th>P-Value</th>
<th>Best Practices</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructability</td>
<td>0.068*</td>
<td>Risk Assessment</td>
<td>0.600</td>
</tr>
<tr>
<td>Team Building</td>
<td>0.015**</td>
<td>Material Management</td>
<td>0.905</td>
</tr>
<tr>
<td>Alignment</td>
<td>0.014**</td>
<td>Planning for Start up</td>
<td>0.507</td>
</tr>
<tr>
<td>Partnering</td>
<td>0.046**</td>
<td>Safety</td>
<td>0.807</td>
</tr>
<tr>
<td>Front End Planning</td>
<td>0.035**</td>
<td>Dispute Prevention</td>
<td>0.825</td>
</tr>
<tr>
<td>Change Management</td>
<td>0.025**</td>
<td>Quality Management</td>
<td>0.392</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lesson Learned</td>
<td>0.502</td>
</tr>
</tbody>
</table>

** denotes significant differences with 95% confidence; * denotes significant differences with 90% confidence

As illustrated in Table 4, according to the CII (IR-166-3), the total cost saving of projects associated with six significant BPs, are mentioned. Implementing Partnering, Alignment, Front End Planning, and Constructability leads to 10%, 9.8%, 10%, and 4.3% cost saving, respectively. In addition, implementation of Change Management and Team Building are beneficial for cost saving. The last column in Table 4 displays information related to the description of BPs.
Implementing Change Management strategy would enhance the project cost performance by establishing a professional baseline agreement and using classification process. By this classification, team members are able to recognize any change early in a project. Partnering promotes continuous improvement of quality of products and services that leads to cost saving. With more effective utilization of resources caused by implementing Partnering, cost effectiveness for each organization would be achievable.

![Implementation Level of BPs](Image)

**Figure 4. Comparison of BPs’ implementation level based on project complexity level**

Alignment strategy adoption leads to effective project leadership, which causes alignment of attitudes, values, and environment of team members. Ultimately, this best practice prevents schedule delays that interrelate with cost saving directly. Building the project team, including owner stakeholders and consultants, is included in utilization of Font End Planning strategy. This building project team inherently leads to effective cost performance. Constructability adoption by contractors is highly recommended to minimize rework and errors in design and construction phases. Consequently, less duration and more cost saving would be obtained. Utilization of Team Building enhances trust and accountability among project participants, and also creates shared goals between stakeholders. Therefore, with adoption of Team Building reduction in potentially time-consuming disagreements and conflicts would be achievable.

**Table 4. Best Practices’ Descriptions and Their Associated Cost Saving Benefits**

<table>
<thead>
<tr>
<th>Best Practice</th>
<th>BP Impact</th>
<th>BPs Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change Management</td>
<td>Cost Savings</td>
<td>An organization’s process of incorporating a balanced change culture of recognizing, planning, and evaluating project changes to manage them.</td>
</tr>
<tr>
<td>Partnering</td>
<td>10% cost saving</td>
<td>A long-term commitment between several organizations, as in alliance, or it may apply to a shorter period of schedule.</td>
</tr>
<tr>
<td>Alignment</td>
<td>9.8% cost saving</td>
<td>The condition under which project participants are working within acceptable tolerances to develop a uniformly defined set of objectives.</td>
</tr>
<tr>
<td>Front End Planning</td>
<td>10% cost saving</td>
<td>The process through which owners develop sufficient strategic information to address risk in order to maximize project success.</td>
</tr>
<tr>
<td>Constructability</td>
<td>4.3% cost saving</td>
<td>The effective integration of construction knowledge into all phases of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost effective levels.</td>
</tr>
<tr>
<td>Team Building</td>
<td>Cost Savings</td>
<td>A project-focused process that develops shared goals, interdependence, trust and commitment among team members. It also seeks to improve team members’ problem-solving skills.</td>
</tr>
</tbody>
</table>
CONCLUSION

The intent of this paper was to study the impact of complexity on cost overruns/underruns of construction projects in three phases of design/engineering, procurement and construction. This study concluded that the cost performance of design/engineering and construction phases in high complexity projects was significantly better than low complexity ones. On the contrary, the cost performance of low complexity projects in procurement phase was significantly better than high complexity ones. In this respect, the phase-based impact of complexity indicators on cost performance of a high complexity project was studied and presented. The results demonstrated that “high number of joint-venture partners”, “number and/or difficulty level of funding phases”, and “number and/or difficulty level of obtaining permit” are the indicators, which have significant impact on cost performance of all three phases. In the last part of the presented study, to investigate the underlying root causes of better cost performance of high complexity projects compared to low complexity ones, the implemented strategies were studied. It was concluded that Constructability, Team Building, Alignment, Partnering, Front End Planning and Change Management strategies were significantly more implemented compared to low complexity ones. This study assists PMs to allocate human and machinery resources as well as implement appropriate BPs in high complexity projects to obtain optimum phase-based cost performance in construction projects. In addition, this study helps PMs to precise predict and estimate phase-based behaviour of cost performance in complex projects, and allocate appropriate resources efficiently in complex projects.

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