Entity-Based Investigation of Project Complexity Impact on Size and Frequency of Construction Phase Change Orders

Elnaz Safapour, S.M.ASCE¹, Sharareh Kermanshachi, Ph.D., M.ASCE², and Issa Ramaji, Ph.D.³

1 Ph.D. Student, Department of Civil Engineering, University of Texas at Arlington, 425 Nedderman Hall, 416 Yates Street, Arlington, TX 76019. E-mail: elnaz.safapour@uta.edu
2 (Corresponding author) Assistant Professor, Department of Civil Engineering, University of Texas at Arlington, 425 Nedderman Hall, 416 Yates Street, Box 19308, Arlington, TX 76019. E-mail: sharareh.kermanshachi@uta.edu
3 Assistant Professor, College of Computing, Engineering, and Construction, University of North Florida, 2122 Building 50, Jacksonville, FL 32224, E-Mail: issa.ramaji@unf.edu

ABSTRACT

Many large-scale construction projects suffer from issuance of construction phase change orders that ultimately leads to significant cost overruns and major scheduling delays. Researchers and practitioners have found complexity, as well as several project characteristics, to be the underlying cause of change orders. Therefore, the aim of this study was to investigate and analyze the impact of a project’s level of complexity on the value and number of change orders issued by each of the three primary stakeholders (owner, designer and contractor) during the construction phase. To fulfill the objectives of this study, a survey questioning about the project characteristics was developed and distributed. After two follow-up emails, 44 complete survey responses were collected. Thirty were related to high complexity projects, and the rest were related to low complexity projects. The value and number of change orders dispensed during the construction phase by owners, engineers, and contractors for high and low complexity projects were studied and compared. Depending on the type of collected data, the two-sample t-test and analysis of variance (ANOVA) were utilized. Results revealed that there is a significant difference between the number of change orders issued for low and high complexity projects. Owner and contractor stakeholders issued significantly more change orders for high complexity projects than for low complexity ones during the same phase. Further investigation showed that for high complexity projects, the owner stakeholder derived the maximum value for a minimum number of change orders. For low complexity projects, the contractor stakeholder derived the maximum number and value of change orders. Finally, the impact of the complexity indicators on change order types (scope creep and rework) in complex projects was studied. The results revealed that the three primary determining indicators leading to issuance of scope creep and rework change orders in complex projects are directly related to the total number of joint venture partners in a project, the number of funding phases from concept to project completion, and the number of executive oversight entities above the project management level. The intent of this paper is to help project managers (PMs) accurately estimate the value and number of change orders derived by each of the three types of stakeholders, and to predict the behavior of complexity indicators on the issuance of scope creep and/or rework change orders at an early stage of a project. This would assist PMs to plan proactively to prevent change orders and related financial contingencies.

INTRODUCTION

Uncertainty and complexity are inherent in construction projects due to the nature of the industry, affecting ultimate Engineering, Procurement and Construction phase cost and schedule
performance (Safapour, 2018). Researchers believe that these problems can be alleviated by a proactive complexity management plan. For many years, researchers had challenges because of the lack of a standard definition for project complexity (Sinha et al. 2001). However, several recent studies provided a constructive approach in determining (Dao et al. 2016), assessing and managing (Kermanshachi et al 2016a & 2016b) project complexity. They defined project complexity as “the degree of differentiation of project elements, interrelatedness between project elements, and consequential impact on project decisions.” In addition, they identified and categorized 34 complexity indicators, which they grouped into 11 categories: stakeholder management, governance, legal, fiscal planning, interfaces, scope, location, design and technology, project resources, quality management, and execution (Dao et al. 2016).

Change orders are a derived in construction projects due to the uncertainties and complexity of the projects (Kermanshachi, 2017). The impact of change orders on the execution of construction projects are cost overruns, scheduling delays, and decreased productivity. Based on the uniqueness of each construction project and its cost and schedule estimation, change orders and their undesired consequences vary substantially from project to project. Change orders are usually issued to modify the scope of work and/or design during the construction phase and are derived for various reasons by different entities. In addition, they have the potential to create serious challenges for owners, engineers, and contractors, and may also lead to adversarial relationships and conflicts among the project stakeholders. To investigate the underlying causes of change orders, researchers explored the premise that the complexity of a project is one of the causes of change orders in construction projects (Chan & Kumaraswamy 1997, Hsieh et al. 2004).

Since change orders are an underlying cause of cost overruns, the authors of the present study decided to investigate the impact of complexity on the issuance of change orders, with the following objectives: (1) investigate the differences between high and low complexity projects, based on the value and number of change orders issued by each of the three stakeholders through the construction phase, (2) identify the entities that issue change orders in high and low complexity projects during the construction phase, and (3) identify the impact of complexity indicators on change order forms, scope creep, and rework in complex projects. The outcomes of this study are intended to help PMs accurately estimate the value and number of change orders issued by each entity early in the construction phase and to plan proactively to prevent untimely change orders and financial contingencies.

**LITERATURE REVIEW**

For many years, there had not been a standard definition within the construction community for complexity terminology. Baccarinni (1996) explained complexity as an intrinsic property of a system, and regarded it as a technological and organizational complexity, inciting researchers to attempt to quantify it. Dao et al. (2017) stated that complexity is often used interchangeably with two concepts: project difficulty and project risk. Complex projects involve barriers which make it difficult to attain the objectives of the project and uncertainty is related to the unknowns and unpredictable events of the project (Kermanshachi, 2016). Cicmil et al. (2006) believed that complexity is often a part of project management and has been defined as one of the most fundamental characteristics of projects. Scholars have tried to quantify complexity levels in projects by measurement factors and categorizations (Gransberg et al. 2013, He et al. 2015).

Change orders are unavoidable in the construction industry, which has been described as inherently uncertain and complex. A significant number of studies has been conducted to investigate the root causes of change orders and their undesired consequences on construction
projects (Kermanshachi, 2018). Moselhi et al. 2005, Gerald et al. 2007, and Kean et al. 2010 grouped the root causes of change orders into three categories; owner-derived change orders, consultant-related change orders, and contractor-related change orders. Owner stakeholders usually issue change orders to modify the scope of the projects, and the consultant and contractor entities commonly issue change orders to correct or modify the original design of projects (Kermanshachi, 2017). Change orders in the design phase are totally unlike those of the construction phase; therefore, they are considered as two separate functions. It is very unlikely that a project can be delivered without any change orders during both the design and construction phases (Ssegawa et al. 2002).

**RESEARCH METHODOLOGY**

A five-step research approach was developed to address the objectives of the present study. As is illustrated in Figure 1, the first task was to review the existing literature to determine the potential impact of complexity on the issuance of change orders in construction projects. The study questions and objectives were determined to direct the study around the focus point. In the second task, forty-four case studies and information regarding high and low complexity projects were collected, based on the value and number of change orders initiated by each of the three entities through the construction phase. The stakeholders were owners, engineers, and contractors. Thirty of the projects were high complexity projects, and the rest were low complexity projects. Qualitative data analysis was utilized to investigate the difference between high and low complexity projects, based on the value and number of change orders issued by each entity in the construction phase.

**Task 1: Literature review (Define research objectives)**
**Task 2: Data collection (Case study data collection)**
**Task 3: Qualitative analysis (Comparative Analysis)**
**Task 4: Quantitative analysis (Two-sample t-test, ANOVA test)**
**Task 5: Discussion of the findings (Interpretation of results)**

**Figure 1. Research methodology process**

In Task 4, two-sample t-test was utilized to answer the following research question between two groups of high and low complexity projects:

**Research Question 1:** Is there a significant difference between the mean value/number of change orders that each entity derived in high and low complexity projects?
- Null Hypothesis (H0) – There is no difference between the entity-based mean value/number of change orders in high and low complexity projects.
- Alternative Hypothesis (H1) – There is a significant difference between the entity-based mean value/number of change orders in high and low complexity projects.

Then, ANOVA test was utilized to answer the second research question of this study examining the role of the three primary stakeholders in deriving change orders.

**Research Question 2:** Is there a significant difference between the mean value/number of the derived change orders across the three primary stakeholders?
For the last research question, two-sample t-test was used to test the difference between two groups which is explain in detail later in the paper.

**Research Question 3:** Which of the 34 complexity indicators (Dao et al. 2017) have a significant impact on the change orders’ forms in complex projects?
In the final task, the results were discussed and interpreted.

**DATA COLLECTION AND PRELIMINARY DATA ANALYSIS**

The academic research team members developed a set of potential change orders indicators (potential cause of change orders) among high complexity indicators (Dao et al, 2017) based on the literature reviews. Each potential change orders indicator became one question of a questionnaire. The survey questions were categorized into two following sections: (1) general project description, and (2) complexity indicators (Dao et al., 2017) which could derive change orders. Figure 2 shows two example questions of the developed survey.

To avoid respondents’ confusion, the definitions of the related terminologies were included in the survey. After the questionnaire framework was developed, a pilot test was performed to test the clarity of each question. The survey was pilot tested by four industry experienced practitioners. After the questionnaire was validated, it was finalized distributed among potential industry respondents. The survey process was entirely conducted online. After two follow-up emails, the team received 44 completed survey responses.

**Question 9.** Please complete the following table with respect to change orders after authorization?

<table>
<thead>
<tr>
<th></th>
<th>Total Change Orders Throughout Construction Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner Driven</td>
<td>Number: _______  Value: _______</td>
</tr>
<tr>
<td>Engineering Driven</td>
<td>Number: _______  Value: _______</td>
</tr>
<tr>
<td>Contractor Driven</td>
<td>Number: _______  Value: _______</td>
</tr>
</tbody>
</table>

**Question 23.** Were there joint-venture partners in this project? If yes, how many?

**Figure 2.** Two example questions of the survey

Of the 44 collected survey projects, 30 belonged to heavy industrial projects, and the remaining 14 belonged to light industrial projects, infrastructure projects, and building projects. The average cost was $284 million, with a maximum value of $5.6 billion, and minimum value of $0.4 million. The average duration of the projects was 28 months, with a maximum of 70 months and a minimum of 8 months. In terms of the selection of the project delivery method, 34% of the projects selected the design-build, 32% adopted the design-bid-build, 25% selected multiple-primes, and 8% selected construction management at risk. Forty-eight percent (48%) of the projects utilized lump sum contracts, and the rest used cost-reimbursable contracts.

The impact of the complexity level on the entity-based value and number of change orders was investigated. Since most of the value and number of change orders are issued in the construction phase, this was the focus point of the study. As shown in Figure 3, box plots were used to illustrate the differences between high and low complexity projects based on the entity-based value and number of change orders in the construction phase. The results revealed that the values of change orders in high complexity projects are significantly higher than those of low complexity ones, and the number of change orders derived by owners and contractors for high complexity projects was significantly higher than for low complexity ones. The median value of owner-derived change orders in high complexity projects was approximately $1200 dollars higher than for the low complexity ones. The median value of engineering-and contractor-initiated change orders for high complexity projects was roughly $600 to $1,000 higher than for low complexity
projects in the same phase. Furthermore, the median number of engineering-derived change orders in high and low complexity projects was approximately 15.

Figure 3. Comparative analysis of complexity impact on entity-based value and number of derived change orders

STATISTICAL DATA ANALYSIS AND RESULTS

The two-sample t-test was utilized to statistically analyze the mean value/number difference of entity-based change orders during the construction phase between high and low complexity projects. For instance, Two-sample t-test was utilized to statistically test the mean value difference of owner derived change orders between low and high complexity projects. The results are shown in Table 1. For the performed statistical test, the value of the change orders issued by each entity in high complexity projects was significantly different from low complexity ones. The outcome of the analysis revealed that the value of the change orders issued by each entity for high and low complexity projects in the construction phase are statistically different. In addition, the number of owner- and contractor-derived change orders of high complexity projects are statistically different from those of the low complexity projects in the same phase.

Table 1. P-Value test results for complexity impact on value & number of derived change orders within each entity

<table>
<thead>
<tr>
<th>Variables</th>
<th>Change Order Deriving Entity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Owner</td>
</tr>
<tr>
<td>Value of Derived Change orders</td>
<td>0.048**</td>
</tr>
<tr>
<td>Number of Derived Change Order</td>
<td>0.024**</td>
</tr>
</tbody>
</table>

** denotes significant differences with 95% confidence; * denotes significant differences with 90% confidence
As illustrated in Figure 4, the portion of each entity’s issued value of change orders in high complexity projects during the construction phase was investigated. Among the stakeholders, the owner entity had the maximum portion of value of change orders (60%) for high complexity projects; the engineering entity’s portion was 18%. In the same analysis for low complexity projects, the contractor and owner entities issued maximum (63%) and minimum (10%) values of change orders, respectively. Owner entities commonly issue change orders pertaining to scope creep, and contractor and engineering entities usually issue change orders for rework. Therefore, it is concluded that the maximum portion of the value of change orders for high complexity projects is related to scope creep, and the maximum portion of value of change orders for low complexity projects is related to rework.

![Figure 4. Complexity impact on value of entity-based derived change orders](image)

As shown in Figure 5, among the stakeholders, the contractor entity issued the maximum portion of number of change orders (approximately 50%) for both high and low complexity projects. Using the same analysis for both high and low complexity projects, the minimum portion was associated with the owner stakeholder. These analyses indicate that the owner entity issued maximum value and minimum number of change orders in high complexity projects, and the contractor issued the maximum value and maximum number of change orders for low complexity projects. The significant statistical differences between values of change orders issued by each of the three entities in the construction phase were studied for both high complexity and low complexity projects during the construction phase. The same analysis was performed for the number of change orders derived by three stakeholders for both high complexity and low complexity projects. ANOVA was utilized to perform the required statistical tests and compare the mean between value/number of change orders of three stakeholders (owner, engineering, and contractor) in high and low complexity projects. The results were shown in Table 2.

![Figure 5. Complexity impact on number of entity-based derived change orders](image)

The results demonstrated that in high complexity projects, there was significant difference between the values of change orders issued by each of three entities. In addition, the same result
was obtained for the number of change orders derived by the three entities. The same analysis of low complexity projects revealed that there was no statistical significant difference between values of change orders derived by each of three stakeholders during construction phase. The same results were obtained for the number of change orders derived by the three entities in low complexity projects.

Table 2. Significance Test Results between Value and No. of Change Orders Derived by Each of Three Entities in High and Low Complexity Projects in Construction Phase

<table>
<thead>
<tr>
<th></th>
<th>Value of Change Orders</th>
<th>Number of Change Orders</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Complexity Projects</td>
<td>0.06*</td>
<td>0.058*</td>
</tr>
<tr>
<td>Low Complexity Projects</td>
<td>0.478</td>
<td>0.254</td>
</tr>
</tbody>
</table>

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

The last step of this study focused on the impact of complexity indicators on the issuance of two change order forms (scope creep and rework) in complex projects. The procedure employed for this step is shown schematically in Figure 6. It is important to note that every complexity indicator is addressed by a physical and a managerial characteristic of the project, and is also associated with the corresponding stakeholder. All 34 complexity indicators were categorized into three primary stakeholders: owners, engineers, and contractors. Two causes and effects (Cause & Effect 1 and Cause & Effect 2) are included in this figure. In Cause & Effect 1, each complexity indicator leads to a specific cause of the change order that is mentioned in the literature. For instance, increasing the number of joint venture partners was defined as one of the complexity indicators (Chao et al., 2017). In addition, slow decision making was identified as one of the causes of change orders (Chan and Kumaraswamy 1997). In Cause & Effect 1, with an increasing number of joint venture partners, a delay in decision making could occur. In the second Cause & Effect, Effect 1 is assumed as Cause 2. Therefore, the causes of change orders lead to their issuance. As explained earlier, change orders have two forms: scope creep and rework. The owner stakeholder is commonly responsible for scope creep, and engineering and contractor entities are commonly responsible for rework. Therefore, the value of owner-issued change orders usually means the value of scope creep, and the engineering-and-contractor-issued value of change orders is commonly considered as rework. As illustrated in Figure 6, the contribution of this research is investigation into the impact of complexity indicators on the issuance of scope creep and/or rework change orders. The two-sample t-test was utilized to determine which form of change orders was issued by each complexity indicator.

![Figure 6. Investigative procedure of complexity indicators impact on scope creep & rework](image-url)
Table 3 has five columns. The first one is related to the three entities that are responsible for driving corresponding complexity indicators. The second and third columns contain a list of complexity indicators and causes of change orders, respectively. The last two columns are related to the results of statistical test. Two-sample t-test was utilized to observe if there is significant difference between the mean values of change orders of two groups. To explain in detail, for instance, there are two groups of projects which either have formed joint-venture partners or have not formed any joint-venture partners (CI-4). Two-sample t-test was utilized to observe that there is significant difference between mean values of owner-based change orders (scope creep) of two mentioned groups. It is important to note that the abbreviation of CI (Complexity Indicator) and the following numbers (e.g. CI-4) in Table 3, are the same as the original ones in the research of Dao et al. (2017).

Table 3. Impact of Complexity Indicators on Deriving Scope Creep and/or Rework

<table>
<thead>
<tr>
<th>Entity</th>
<th>Complexity Indicator</th>
<th>Change Orders Causes</th>
<th>Scope Creep</th>
<th>Rework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
<td>CI-4-Total number of joint-venture partners in a project.</td>
<td>Low speed of decision making (Chan and Kumaraswamy, 1997)</td>
<td>0.077*</td>
<td>0.02**</td>
</tr>
<tr>
<td></td>
<td>CI-5-Number of executive oversight entities above the project management.</td>
<td>Low speed of decision making (Chan and Kumaraswamy, 1997)</td>
<td>0.001**</td>
<td>0.02**</td>
</tr>
<tr>
<td></td>
<td>CI-7-Number of funding phases from concept to project completion.</td>
<td>Delay in payment (Karthick et al., 2015)</td>
<td>0.023**</td>
<td>0.044**</td>
</tr>
<tr>
<td></td>
<td>CI-17-Compare target project schedule against industry/internal benchmarks.</td>
<td>Poor scheduling (Wu et al., 2004)</td>
<td>0.035**</td>
<td>0.221</td>
</tr>
<tr>
<td></td>
<td>CI-18-Difficulty in system design.</td>
<td>Mistake and defect in design (Chan and Kumaraswamy, 1997/Hsieh et al., 2004)</td>
<td>0.196</td>
<td>0.094*</td>
</tr>
<tr>
<td></td>
<td>CI-24-Impact of project location on the project execution plan.</td>
<td>Site safety consideration (Hsieh et al., 2004)</td>
<td>0.037**</td>
<td>0.146</td>
</tr>
<tr>
<td></td>
<td>CI-12-Difficulty in obtaining design approval.</td>
<td>Long waiting time for approval (Chan and Kumaraswamy, 1997)</td>
<td>0.441</td>
<td>0.07*</td>
</tr>
<tr>
<td></td>
<td>CI-19-Degree of familiarity with technologies in design project.</td>
<td>Defect in design (Hsieh et al., 2004)</td>
<td>0.257</td>
<td>0.041**</td>
</tr>
<tr>
<td></td>
<td>CI-22-Number of execution locations on this project during detailed engineering/design phase.</td>
<td>Inappropriate linking all design team (Chan and Kumaraswamy, 1997)</td>
<td>0.706</td>
<td>0.015**</td>
</tr>
<tr>
<td></td>
<td>CI-25-Percentage of design completed at the start of construction.</td>
<td>Incomplete design information (Jadhav and Bhirud, 2015)</td>
<td>0.215</td>
<td>0.093*</td>
</tr>
<tr>
<td></td>
<td>CI-29-RFI leads to design changes.</td>
<td>Changes in construction method (Wu et al., 2004)</td>
<td>0.665</td>
<td>0.08*</td>
</tr>
<tr>
<td></td>
<td>CI-9-Quality of bulk materials</td>
<td>Replacement of material (Karthick, 2015)</td>
<td>0.724</td>
<td>0.056*</td>
</tr>
<tr>
<td></td>
<td>CI-20- Familiarity with technologies in construction phase.</td>
<td>Changes in construction method (Wu et al., 2004)</td>
<td>0.632</td>
<td>0.005**</td>
</tr>
<tr>
<td></td>
<td>CI-30-Percentage of actual project management staff.</td>
<td>Poor site management and supervision (Chan and Kumaraswamy, 1997)</td>
<td>0.136</td>
<td>0.011**</td>
</tr>
</tbody>
</table>

In the case of CI-4, increasing the number of joint venture partners in a project leads to the involvement of more primary stakeholders who have authority for decision-making. This can present problems pertaining to decision-making and consensus due to miscommunication between stakeholders and could significantly increase the possibility of a greater number of scope creep and rework change orders. CI-17 shows that if the project schedule is shorter than the industry/internal standard benchmark, schedule delays will occur, leading to cost overruns. In the case of CI-18, if the design of a system is difficult, the number of errors and mistakes will increase.
due to the lack of knowledge and/or experience of those designing the complex system. Ultimately, these errors will significantly cause several reworks and modifications during the construction phase. In regard to CI-9, the poor quality of materials in the construction phase of a project is considered as an indicator that leads to replacement of the material. Material replacement is usually due to an extension of the construction time or modification of the design. In general, the possibility of scope creep occurring increases when the complexity indicator is associated with the owner entity. Likewise, the possibility of rework increases when the complexity indicator is associated with engineers and contractors.

CONCLUSION
The entity-based investigation of the impact of the level of complexity of a project on the value and number of change orders was studied in this paper. It was concluded that the value of change orders of high complexity projects is significantly higher than for low complexity projects during the construction phase. In addition, the owner and contractor stakeholders issued significantly more change orders for high complexity projects than for low complexity ones in the mentioned phase. Then, the portion of each entity that derives change orders was investigated. The results demonstrated that the owner and contractor entities issue the maximum value of change orders for both high and low complexity projects. The contractor stakeholder issues the maximum number of change orders for both high and low complexity projects. Finally, the impact of complexity indicators on the issuance of change orders for scope creep and rework was studied. This study revealed that the total number of joint venture partners in a project, the number of funding phases from concept to project completion, and the number of executive oversight entities above the project management level were the determining indicators leading to issuance of scope creep as well as rework in complex projects. The findings of this study will assist PMs in accurately estimating the value and number of the change orders that will be initiated by each stakeholder in complex projects and in predicting the behavior of complexity indicators for the issuance of scope creep and/or rework in the early stage of a project.

REFERENCES


