Empirical Analysis of Issue Management in Small Vertical Construction Projects: Relationship between Project Performance, Project Team Actions, and Issue Types

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ABSTRACT

Public institutions seek to maintain their built-environment assets by allocating sizable budgets to small construction projects that renovate or expand upon existing facilities. Small building construction projects are common in the public institutional sector, resulting in cumulative portfolios that are quite sizable for institutions to oversee. Like any other construction project, small building projects are fraught with issues that threaten to cause deviations (mostly negative) from their base cost, schedule, and quality. Therefore, even smaller magnitude of cost and schedule growth on projects, can quickly cumulate to millions of dollars and months of schedule delay across the entire portfolio. Project control techniques can be used reduce the impacts of negative performance outcomes. Previous studies indicate that these issues are commonly caused by owner factors, designer factors, contractor factors, and unforeseen circumstances, and are widespread in all type of construction irrespective of project type, owner type, procurement type, project delivery type, and project size. Despite their collective volume, relatively little research has focused on the performance of small building projects or investigated issue management practices within small building projects. This study aims to address the gap by analyzing the most common issues that occur during the construction phase of the small building construction projects, its impact on project performance outcomes, and the project team extent and consistency with which project teams utilize issue logs to monitor, control, and resolve issues. The study's dataset consisted of 881 small building projects, including 5,236 individual issues that the project teams identified, monitored, and resolved during the construction phase. The results of this study shows that the most frequently occurring issues were designer and owner related. Design errors and omissions and unforeseen concealed conditions were typically identified and resolved the earliest in the schedule, whereas contractor-related issues were typically the last to be identified and resolved. Further, it was found that the different issues impacted the cost and schedule growth differently, where owner-caused scope changes and other internal issues within the owner organization were the primary causes of cost and schedule growth, whereas contractor-caused issues and unforeseen weather conditions were the least problematic causes. Lastly, it was found that on average project teams who practiced issue management implementation to a greater extent achieved a 3.1 to 4.3 percent reduction in cost growth and a 5.3 to 12.3 percent reduction in schedule growth, and the level of issue log usage during the first quartile of the project schedule was indicative of the project team's behavior for the remainder of the project. This study adds to the body of knowledge by analyzing a relatively understudied topic of issue management in the literature, which is even scarcer in the small building construction projects. Furthermore, this study quantifies the project performance outcomes for different issues using a relatively larger sample size of 881 small building projects. These results can also help project teams by focusing on the issues that occur at a higher frequency and results in the greatest cost and schedule growth and thereby take proactive measures to minimize negative impacts to project performance. Moreover, project teams should be encouraged to establish their issue management practices early in the project schedule to encourage greater issue log usage for the remainder of the project for favorable project performance outcomes.

DISSERTATION FORMAT

This dissertation follows the three-journal-paper format. Chapter 1 consist of a brief introduction of the research, research questions and point of departure, research outline. Chapters 2, 3, and 4 are formed as three journal papers. More precisely, Chapter 2 of this dissertation identifies the most common issues that occur during the construction phase of small building project and how project team identified, monitored, and resolved by the project team. Chapter 3 of this dissertation analyzes the most common issues their impact on project cost and schedule growth. Chapter 2 and 3 were published in the *International Journal of Construction Education and Research* under the title "An Empirical Analysis of the Causes of Cost and Schedule Growth for Small Healthcare and Educational Construction Projects" and "An Empirical Analysis of Issue Management in Small Building Construction Projects," respectively. Chapter 4 of this dissertation analyzes the project team's extent and usage of issue management to monitor and control cost and schedule growth, and is published in Emerald Publishing' *Engineering, Construction, and Architectural Management,* under the title of "Using Issue Logs to Improve Construction Project Performance." Finally, Chapter 5 provides a cohesive conclusion to all the analysis and provides recommendations for best practices that can be used for industry professionals along with recommendations for future research. Additional related tables, figures, and graphs used in this dissertation were coalesced in the Appendices section. Specifically, Appendix A includes a template of the issue log used in this study along with how issues were defined in a diagrammatic manner. Appendix B includes descriptive analysis, such as bar charts, histograms, scatter plots, and bubble charts that were used as supporting analysis. Appendix C includes a list of sub-hypothesis statements and inferential testing, mainly post-hoc tests, that were too voluminous to be inserted in the main body.

To my family and friends

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CHAPTER 1: INTRODUCTION

BACKGROUND

Construction projects are prone to issues that cause deviations from the contracted cost, schedule, and quality (Larsen et al. 2015). Project control techniques can be used reduce the impacts of negative performance outcomes (Olawale and Sun 2013). Project control can be defined as the data monitoring, management, and analytical processes used to understand and constructively inform decisions that may impact the performance outcomes of a project (Orgut et al. 2020). Effective project control pertains to setting performance objectives for the project, comparing current status with planned and forecasted progress, and then taking corrective actions as needed to maintain a successful project outcome (Hanna 2012). Due to their the importance in the field of professional project management, numerous project control techniques have been developed to assist project managers. For example, the Project Management Institute (PMI) advocates for the usage of numerous project control techniques such as: Earned Value Analysis (EV), Critical Path Method (CPM) scheduling, root cause analysis, trend analysis, variance analysis, To-Complete Performance Index (TCPI), inspections related to scope, quality, and safety, Program Evaluation and Review Technique (PERT), and Risks, Assumptions, Issues and Dependencies (RAID) logs, to name a few (PMI, 2017).

The Project Management Body of Knowledge (PMBoK), published by the Project Management Institute (PMI, 2017), is a collection of terminology, processes, best practices, and guidelines that are accepted as representing a professional standard in the project management industry. PMI is also the credentialing power behind the widely recognized Project Management Professional (PMP) certification. PMI’s influence is strong in the construction industry, where the PMBoK and PMP are both well-known as professional standards.

Issue management is one of the project control techniques recommended by the PMBoK. The PMBoK defines an issue as an event that can cause potential changes to any combination of project policies, procedures, scope, quality, and, most commonly, cost and schedule. Issue management includes the practices, tools, and actions that a project team may utilize to identify, communicate, monitor, and resolve the issues that occur on their projects. The PMBoK recommends the use of a tool known as an Issue Log to formalize the issue management approach within a project team's operations, which is a formal tracking method to systematically monitor issues until they are resolved. Although the PMBoK does not provide a standardized Issue Log template, it does recommend certain best practices, including: all stakeholders to report actual and potential issues that could impact the cost and schedule, a consistent format for recording the issues being monitored, regular discussions on the status of each issue in weekly project meetings, development of response plans for resolving active issues, and ongoing updates to forecast potential cost and schedule impact likelihoods.

Construction projects are fraught with issues that threaten to cause negative project performance outcomes (Gündüz et al. 2013). Previous studies indicate that these issues are commonly caused by owner factors, designer factors, contractor factors, and unforeseen circumstances, and are widespread in all type of construction irrespective of project type, owner type, procurement type, project delivery type, and project size (Gardezi et al. 2014). Like any construction project, small building construction projects are also prone to issues, which must be effectively managed by the project teams to avoid negative performance outcomes (Perrenoud et al. 2016). Small building construction projects are common in the public institutional sector, resulting in cumulative portfolios that are quite sizable for institutions to oversee, ranging from millions of dollars to at times in billions (Hurtado et al. 2017). Public institutions seek to maintain their built-environment assets by allocating sizable budgets to renovate and expand upon existing facilities or for new construction. Despite their collective volume, relatively little research has focused on the performance and investigated issue management within the small building projects.

GAP IN THE LITERATURE

Based on a thorough literature review, little previous research has specifically addressed issue management in small building construction projects. Primarily, these gaps in the literature were:

- Limited research was found on the specific topic of issue management in construction, with little research that has analyzed Issue Identification, Issue Resolution, and Issue Monitoring Periods of the issues that occur during the construction phase. Furthermore, research analyzing relationship between issue management and project performance for small vertical construction project was found to be scarce. Given the emphasis placed by the PMBoK on early identification and resolution of an issue, as well as shorter monitoring periods (duration between identification to resolution), this study investigated issue management timing during construction and its relationship with project performance.
- Numerous studies have focused on qualitative identification of issues that impact the project Cost and Schedule Growth (sometimes referred to as sources of change orders, risks or risk factors, and underlying causes of Cost and Schedule Growth, depending on the study terminology and particular definitions). Such studies have historically been limited to identification of issues via interviews, surveys, and mixed methods designs, and are typically aimed at identifying the frequency and relative importance using rank analysis approaches (such as the relative importance index, frequency index, severity index,

importance index, relative importance weight, mean score, rank correlation coefficient, weighted opinion average, and importance weight, etc.) This study utilized empirical data to investigate 5,635 individual issues that occurred during small construction projects in the public institutional sector.

- In the construction literature, numerous studies on the topic of project control have utilized change orders, Cost Growth, Schedule Growth, and potential risk factors as their unit of measure. Relatively few studies have employed individual issues as their unit of measure. This study was designed such that the unit of measure was individual issues that occurred and were managed by the project team during the construction phase. This unit of measure considers additional information related to the challenges faced by construction teams which would be captured by more traditional measures.

- Among previous studies related to construction project performance, the vast majority are limited to horizontal projects, which are mainly in the transportation sector (highways, roads, bridges, etc.) When compared with the horizontal literature, relatively few studies focus on vertical projects and of the studies that do focus on the vertical sector, the data samples tend to include projects of substantial scale (multi-million-dollar projects, often in the tens or hundreds of millions) rather than smaller institutional projects (in the $1M to $5M scale or smaller). A somewhat newer area of investigation in the vertical sector is the construction of new medical facilities, such as hospitals, surgery centers, and other patient care facilities, which also tend to be larger scale and are often delivered via alternative project delivery methods rather than traditional design-bid-build delivery. Of the vertical sector studies that do investigate smaller-scale projects, their sample sizes tend to be somewhat limited; for example, the most comprehensive study included data from 321 projects. With relatively limited data sets in small vertical construction projects–and owing to their large volume and frequency in public institutions–this study compiled a dataset of 881 such projects for analysis.

RESEARCH OBJECTIVES

The objective of the dissertation is to investigate the characteristics of issue management in small vertical construction projects and the extent to which issue management provides an effective project control tool in that setting. To investigate this objective the dissertation is divided in to three research objectives as follows:

- To investigate the frequency with which different Issue Types arise during the construction phase and to identify the timing of the project team's corresponding Issue Management Parameters (Issue Identification, Issue Resolution, and Issue Monitoring Period) to minimize the impact of each issue.
- To investigate the extent to which different Issue Types (which are the underlying causes of change orders) contribute to the overall project Cost and Schedule Growth.
- To investigate how different levels of Issue Management Implementation undertaken by project teams may be related to more favorable project performance outcomes.

DATA SAMPLE

The data used in the study was extracted from Issue Logs collected from 881 small building projects delivered in 19 public institutions from the U.S. and Canada. For each project in the data sample, a formal Issue Log was submitted by the contractor's project team to the owner on a weekly basis and then was finalized upon project completion as part of a formal close-out process. The Issue Log was maintained by the contractor's project team (and was also reviewed and approved by the owner) in accordance with PMBoK recommendations, where the project team was responsible to log each individual issue encountered during construction operations, the entity responsible for the issue, the timing when the issues were identified and resolved, and the resulting impacts on project cost and schedule (if any). The Issue Log was typically the first agenda topic the project teams reviewed during their weekly project meetings. During such meetings, the Issue Log was updated to document progress on active issues, to indicate when issues were resolved and what their cost and schedule impacts were, and to document new issues. Furthermore, the Issue Log also contained the original contracted cost and schedule duration along with the approved final values of project cost and schedule duration.

The data set utilized in this study included projects from the public institutional sector, including higher education, primary and secondary education, municipal governments, and the armed forces. These projects were completed in the years 2003 to 2015 and were referred to as "small vertical construction projects" since all were limited to total project size of less than $5M (with a median size of $597K). Projects in the data set were limited to education and healthcare facilities of similar size and scope. Cumulatively, these institutions provided close-out documentation for 881 completed small building projects, with over 5,635 individual issues that occurred during the construction phase. These projects had an average awarded cost of $935K (median $597K) and ranged from a minimum of $30K to a maximum of $4.8M. Cumulatively, the total awarded cost for the entire data set was $824M and the cumulative final cost was $890M, representing a total cost increase of $66M. These projects had an average project duration of 300 days (median 270), where awarded project schedule durations ranged from 31 days to just over 450 days.

DEFINITION OF KEY VARIABLES

The following section provides an overview of key variables used in this dissertation.

Issue: An issue is defined as a project event that has the potential to impact the project cost, schedule, or scope, therefore requiring an active management response from the project team.

Issue Types: Issue Types are defined as the root-cause of the issue. Eight leading Issue Types were determined based on a literature review. These were the most commonly identified Issue Types to occur during the construction phase of a project. More detailed descriptions of each Issue Type can be found in Chapter 2 of this dissertation and a summary list is provided below:

1. Owner—Internal (OI)
2. Owner—Scope Change (OSC)
3. Contractor—Prime Contractor (CPC)
4. Contractor—Subcontractors and Suppliers (CSS)
5. Designer—Errors and Omissions (DEO)
6. Unforeseen—Concealed Conditions (UCC)
7. Unforeseen—Weather Conditions (UWC)
8. Unforeseen—Other (UO)

Issue Management: Issue Management is defined as the project team's response to an issue; from the time it is encountered by the project team until the time it is resolved. In this study, Issue Management was divided into three categories, which were used as the three dependent variables in Chapter 2:

1. Issue Identification
2. Issue Resolution
3. Issue Monitoring Period

Project Performance: In this study, cost and schedule growth were used as project performance metrics. A more detailed description on Project Performance can be found in Chapter 3.

Project Size: Three categories of Project Size were used in Chapter 3 of this dissertation:

1. Small (<$375,000)
2. Medium ($375,000–$1M)
3. Large ($1M–$5M)

Issue Management Implementation: Issue Management Implementation (IMI) attempts to distinguish the extent to which individual project teams utilized issue management practices in the construction phase. IMI was categorized into three levels of High, Moderate, and Low. A more detailed description of Issue Management Implementation can be found in Chapter 4 of this dissertation.

SUBSEQUENT CHAPTERS

Subsequent chapter of this dissertation follows a 3-paper format and a concluding chapter.

- Chapter 2 of this dissertation was published in the *International Journal of Construction Education and Research* under the title "An Empirical Analysis of Issue Management in Small Building Construction Projects."

  The full reference for the published paper is provided below:

  Shalwani, A., and Lines. B. C. (2020). "An Empirical Analysis of Issue Management in Small Building Construction Projects." *International Journal of Construction Education and Research*, 1-21.

- Chapter 3 of this dissertation was published in the *International Journal of Construction Education and Research* under the title "An Empirical Analysis of the Causes of Cost and Schedule Growth for Small Healthcare and Educational Construction Projects."

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  Shalwani, A., and Lines, B. C. (2020). "An empirical analysis of the causes of cost and schedule growth for small healthcare and educational construction projects." *International Journal of Construction Education and Research,* 1-20.

- Chapter 4 of this dissertation was published in the *Engineering Construction and Architectural Management* under the title "Using Issue Logs to Improve Construction Project Performance."

  The full reference for the published paper is provided below:

  Shalwani, A., and Lines, B. C. (2021). "Using Issue Logs to Improve Construction Project Performance." *Engineering Construction and Architectural Management.*

- Lastly, Chapter 5 is the concluding chapter of this dissertation which discusses the overarching objective of this dissertation and recommendations for future research in similar field.

CHAPTER 2: ISSUE TYPES AND PROJECT TEAMS ISSUE MANAGEMENT PRACTICES

INTRODUCTION

Small building projects make up sizable portion of the construction programs within public institutions. Although these types of projects are small compared to capital projects in the horizontal and vertical sectors, a single institution’s construction program may deliver a large number of small building projects each year, which in turn represents a substantial total construction budget (Perrenoud, Lines, and Sullivan, 2014). As the facilities that are owned and operated by public institutions continue to age, they require renovation, remodeling, and expansion work. The widespread need for this type of construction work has been consistently shown across the public sector, whether the facilities are public primary and secondary school buildings (NCES, 2014), university campuses (Isa and Usmen, 2015), or healthcare facilities (Call, Sullivan, and Smithwick, 2018). With aging institutions and the large cumulative dollar value that small building projects represent, it is essential that the projects are managed effectively to minimize the risk of cost overruns, schedule delays, and quality issues (Badger and Gavin, 2007).

Construction projects, including small building projects, are prone to a variety of issues that may affect project cost, schedule, and quality (Perrenoud, Smithwick, Hurtado, and Sullivan, 2016). For the purposes of this study, *issues* are defined as project events that have the potential to affect the project cost, schedule, or scope, therefore requiring an active management response from the project team. The Project Management Institute (PMI) endorses effective issue management techniques as a tactic to reduce or even eliminate negative impacts and achieve better project performance. In the project management literature, studies have identified several key factors in minimizing issue impacts, including prompt identification, transparent communication among project stakeholders, and timely response (Mir and Pennington 2014).

Research on issue management in construction projects is limited; instead, the construction literature has primarily focused on change orders and overall cost and schedule growth. Change order research is relevant to the issue management topic in the sense that the individual issues which impact project cost or schedule are eventually processed via a formal change order process. The magnitude, frequency, and timing of change orders is linked to the project performance measures of cost growth, schedule growth, and labor productivity (Ibbs, Nguyen, and Lee, 2007). Presumably, studying issue management may uncover similar linkages. Identifying such links would be of benefit to project teams managing small building projects, enabling them to proactively plan for issue management factors to improve project performance. Further, a limitation of change-order research is that multiple issues are often bundled into a single change order to reduce paperwork and administrative processing time (Anastasopoulos, Labi, Bhargava, Bordat, and Mannering, 2010). Research analyzing individual issues rather than entire change orders will provide a more granular understanding of the day-to-day challenges that construction teams face. This more granular understanding can provide insight regarding which project management practices employees should prioritize to proactively address the most prevalent issues and perhaps prevent them from becoming change orders.

LITERATURE REVIEW

Sources of Negative Project Performance Outcomes in Construction

Construction projects are plagued by performance issues (Cantarelli, Flyvbjerg, and Buhl, 2012). Researchers have investigated the sources of these performance issues in a wide variety of contexts, including in developing countries (Odeh and Battieneh, 2002) and developed countries (Gunduz, Nielsen, and Özdemir, 2013), public owners (Alaghbari, Kadir, and Salim, 2007) and private owners (Sambasivan and Soon, 2007), and in horizontal projects (Ellis and Thomas, 2003) and vertical projects (Sweis, Sweis, Hammad, and Shboul, 2008). The results of these studies indicate that performance issues are commonly caused by owner factors, designer factors, contractor factors, and unforeseen circumstances that occur during construction (Gardezi, Manarvi, and Gardezi, 2014; Shehu, Endut, Akintoye, and Holt, 2014).

Researchers have also identified sub factors in each category that contribute to performance issues. In the owner category, common sub factors include slow decision-making, late contract award, untimely payments, poor communication, and scope changes (Aibinu and Odeyinka, 2006). Designer-related sub factors include errors in construction documents, poor coordination with stakeholders, slow response to inquiries, and poor qualifications of consultants (Alaghbari et al., 2007; Sweis et al., 2008). In the contractor's category, common sub factors include subcontractor and supplier problems, site management, construction methods, improper planning, errors during construction, and inadequate contractor experience (Odeh and Battieneh, 2002; Sambasivan and Soon, 2007). Regarding unforeseen circumstances, the most common sub factors are adverse weather, concealed conditions, inflation, changes in government policies, and unstable country conditions (Gunduz et al., 2013).

Much of the research has involved qualitative surveys. The surveys were typically completed by major stakeholders in construction projects, such as owners, designers, engineers, and contractors; in a few cases, personnel at government agencies were surveyed. The data were typically examined through using rank analysis, such as the relative importance index, frequency index, severity index, importance index, relative importance weight, mean score, rank correlation coefficient, weighted opinion average, and importance weight (Prasad and Venkatesen, 2017).

The factors that cause project issues in large-scale sized projects are also prevalent in small building projects (Perrenoud et al., 2014). In particular, issues within small building projects have been shown to be caused by the owner's team and scope changes, subcontractors or suppliers, the designers' errors and omission, unforeseen concealed conditions, and weather conditions (Perrenoud et al., 2016). Because of the many factors that can cause negative performance outcomes in the construction industry, industry professionals have developed practices to mitigate the issues and the potential negative outcomes.

Issue Management in the Project Management Profession

The Project Management Body of Knowledge, published by the Project Management Institute (PMI, 2017), is a collection of terminology, processes, best practices, and guidelines that are accepted as standard in the project management industry, including when applied to construction. PMI defines *issue* as an event that can cause potential changes, which may affect project policies, procedures, scope, cost, budget, schedule, and project quality. According to PMI, projects should be protected from negative impacts by identifying and resolving individual issues as soon as possible. PMI provides and suggests tools and techniques project teams can use to address project issues; these tools and techniques include workshops, Delphi methods, and brainstorming sessions.

To further assist project teams in applying effective issue-management practices, PMI recommends that project teams document issues via the use of an issue log, which provides a formal tracking system to monitor the issues until they are resolved. Although PMI does not provide a standardized issue log template, PMI does recommend certain best practices, including: all stakeholders to report actual and potential issues that could impact the cost and schedule, regular discussions on the status of each issue in weekly project meetings, development of response plans for resolving active issues, and ongoing updates to forecast potential cost and schedule impact likelihoods. The issue log is used as a formal tracking mechanism of issues that may develop into formal change orders along with the project team's action plan to minimize the potential impact of each issue.

Impact of Change Order Timing and Frequency on Construction Performance

The timing of change orders during the construction phase has been shown to affect project performance. Hanna, Russell, Gotzion, and Nordheim (1999) analyzed 61 mechanical projects and found that when change orders occur later in a project, labor efficiency deceases more than when change orders occur earlier in a project. Moselhi, Assem, and El-Rayes (2005), who analyzed 117 projects, and Ibbs (2005), who analyzed 162 projects of various types, reported similar results. Serag, Oloufa, Malone, and Radwan (2010) analyzed 16 transportation projects and found that the timing of change orders contributes to cost growth.

The frequency of change orders also affects project performance. Shrestha and Maharajan (2018) analyzed 15 transportation projects and found that as the frequency of change orders increases, cost and schedule growth also increase. Anastasapoulos et al. (2010) analyzed over 1,900 transportation projects and concluded that the frequency of change orders has a linear relationship with both cost and schedule growth. Further, Moselhi (2003) analyzed 57 projects of various types and found that the frequency of change orders negatively affects labor productivity.

Issue Management in Construction

Research on issue management—the identification, resolution, and monitoring of individual issues—is limited. The most comprehensive study on issue management was conducted by Perrenoud et al. (2016), which analyzed how various issues during the construction of 229 small building projects affected the cost and schedule. Their study also analyzed the relationship between when an issue was identified and the impact on the cost and schedule. They found that owner scope changes and unforeseen concealed conditions have the greatest impact on cost and owner-related issues had the greatest impact on the schedule. The study also found that when the issues were identified later in the project schedule, they had a greater impact on the cost and schedule. These researchers did not examine the monitoring length nor the timing with which the issues were resolved. The study was also limited to small building projects from a single public entity.

Issue Types in Construction

Previous studies have found a fairly consistent set of issue types within the construction industry. For example, Prasad and Venkatesan (2017) analyzed 53 research articles from 1970 to 2016 including construction projects of various types (building and housing, infrastructure, utilities, etc.) completed in 30 countries and found that the 10 issues had the most impact in developed countries. In this study, 10 issues were coalesced into 8 common issue types due to limitations within the data set. These issue types are described below.

Owner—Internal (OI): These issues involved actions of the owner's various internal stakeholders. The most common of these issues were delays related to the contract documents, owner decision-making, and late payment to contractors.

Owner—Scope Change (OSC): These issues involved the owner's changes to the project's contract documents by adding additional work, directing changes from the originally-provided drawings and specifications, or requesting other alternates.

Contractor—Prime Contractor (CPC): These issues were associated with the prime contractor. The most common were delays in payment of subcontractors or suppliers, poor coordination of work, the need for re-work, and poor supervision of subcontractors.

Contractor—Subcontractors and Suppliers (CSS): These issues were associated with subcontractors and suppliers under the oversight of the prime contractor. For subcontractors, the most common issues were the need to perform re-work to repair faulty or low-quality construction. The most common supplier issues were delays in material delivery, the delivery of incorrect materials, and delivery of defective or poor-quality materials.

Designer—Errors and Omissions (DEO): These issues were associated with errors and omissions in the drawings and construction documents, typically in the form of conflicts between the drawings and specifications or conflicts between different sheets within the drawings.

Unforeseen—Concealed Conditions (UCC): These issues were associated with the discovery of buried or covered materials. The most commonly identified UCC issues were the discovery of deficiencies in hidden structures or presence of unexpected structures or features (e.g. subsurface conditions, buried slabs, etc.), discovery of unexpected artifacts (e.g. archeological artifacts), and the presence of hazardous material (e.g. asbestos, lead paint, etc.).

Unforeseen—Weather Conditions (UWC): These issues involved inclement weather conditions. The most common were snowfall, rainfall, high winds, and dust storms that either impacted or completely shut down construction operations for a period of time.

Unforeseen—Other (UO): These issues involved any other unforeseen circumstances in the project that were not clearly covered by the previous issue types. Examples included unexpected changes in construction environment (e.g. material or labor shortages), unexpected changes in economic conditions (e.g. inflation, recession, material price escalation, etc.), unexpected changes in governmental policies, and civil or labor unrest (e.g. protests, strikes).

RESEARCH OBJECTIVES

Point of Departure

Previous research on construction-phase issue management has primarily utilized qualitative analysis to identify which issues have the greatest impacts on project performance (Prasad and Venkatesen, 2017). A handful of studies have analyzed the timing and frequency of change orders and the associated impact on project performance (Ibbs, 2005; Shrestha and Maharajan, 2018), but little attention has been given to analyzing the timing characteristics of individual issues that are the underlying causes of change orders. The most comprehensive study on issues that occur within construction projects was conducted by Perrenoud et al. (2016), yet the study was limited to 229 small building projects in a single public entity. Another limitation is the study only investigated issue identification and did not consider issue resolution nor the issue monitoring period. Because of the lack of research on issue management in construction along with PMI's (2017) emphasis on monitoring and resolving issues, this study analyzed issues that occurred during the construction phase from more than hundreds of projects across multiple public institutions. Further, the timing with which different issue types were identified, monitored, and resolved was investigated to shed additional light on the issue management practices of construction project teams.

Research Questions and Hypotheses

Studies in the past have quantitatively analyzed the most frequent issues during construction to be owner-, designer-, contractor-, and unforeseen related issues (Shehu et al., 2014; Gardezi et al., 2014). Owing to the lack of empirical analysis related to the frequency of the various types of issues within small building projects, the first objective of the study was to determine how frequently an each of the eight issue types occurred during the construction phase. Based on this objective, the following research question and hypothesis were developed.

Research Question 1: How frequently does each of the eight issue types occur during the construction phase of small building construction projects?

Hypothesis Statement 1 (H1): The eight issue types occur with different frequencies during construction.

Past research has shown that the timing of change orders can affect project performance, such that change orders occurring later in the project schedule often correspond with larger negative impacts to project performance (Ibbs, 2005; Serag et al., 2010). Presumably, the same affect could be hypothesized for the management of individual issues (which may develop into change orders, if not properly managed). However, to test such a hypothesis, it was necessary to determine how the eight types of issues differ in their timing during the construction phase of the project. Accordingly, the following research question and hypothesis were developed.

Research Question 2: To what extent are the issue types identified and resolved at different points in time during the construction phase of small building projects?

Hypothesis Statement 2 (H2): The eight issue types are identified and resolved at different points of time during the construction phase.

PMI has recommended early identification of issues followed by a quick resolution, wherever possible. Similarly, past research has provided similar recommendations in the construction and project management literature (Mir and Pennington 2014). This goes on to show that in addition to early identification, early resolution is encouraged, so that an issue is not held active on the project for longer than necessary. This led to the development of the third and last objective, to determine if different types of issue had different monitoring period during construction.

Research Question 3: To what extent do the issue types have different monitoring periods during the construction phase of small building projects?

Hypothesis Statement 3 (H3): The eight issue sources measured in this study will have different monitoring period durations.

RESEARCH METHODOLOGY

Data Collection

The data used in this study was collected from 19 public institutions. The researchers were actively involved with data collection during the construction phase of each project, wherein weekly issue logs were received from each project team. Wherever possible, the researchers participated in the weekly project management meetings for the projects to verify the accuracy of reported issues with day-to-day project operations. Finally, the researchers received project close out documentation from each of the project teams, which was submitted by the contractor's project manager for review and approval by both the owner's construction manager and procurement representative. The project close out documentation contained the contracted cost and schedule, final cost and schedule, list of all change orders, and the final issue log. This close out documentation was compiled from completed projects to be analyzed in this study.

The data set included 881 construction projects within public education and healthcare facilities. The 287 educational projects in the data set were limited to construction work that occurred in classrooms, dormitories, dining centers, kitchens, offices, and basic teaching and research laboratories. The 594 healthcare projects in the data set were limited to construction work that occurred in office spaces, common areas, dining centers, kitchens, convenience shops, and basic laboratory and general patient care facilities. The data set did not contain complex healthcare construction such as operating rooms or high-level research laboratories; therefore, the scope of construction work in both educational and healthcare projects was held to be reasonably similar. These projects were completed in years 2003 to 2015 and were referred to as small building projects since most were renovation, all were limited to total project size of less than $5M, and the average awarded cost was less than $1M. These project size characteristics are in line with previous studies that have investigated small building projects (Perrenoud et al., 2014, Perrenoud et al., 2016, Shehu et al., 2014). A further demographic break down of the data set can be seen in Table 1.

The data utilized in study was empirical data from projects from 19 public institutions across the United States and Canada, delivered via the Design-Bid-Build (D-B-B) method. These institutions included higher education, primary and secondary education, municipal governments, and the armed forces (see Table 1). Cumulatively, these institutions provided close-out documentation for 881 completed small building projects. These projects had an average awarded cost of $935K and ranged from a minimum of $30K to a maximum of $4.8M. Cumulatively, the total awarded cost for the entire data set was $824M and the cumulative final cost was $890M, representing a total cost impact of $66M. The average project duration was 300 days.

Table 1. Summary of Dataset

Demographics	**Value**
Owner Type	
University	236
Armed Forces	594
City/State/Federal	51
Project Type	
Educational	287
Healthcare	594
Year of Completion	
2003 - 2010	739
2011 - 2015	142
Awarded Cost	
Mean awarded cost	$935,000
Median awarded cost	$597,000
Standard deviation of awarded cost	$976,000
Minimum awarded cost	$30,000
Maximum awarded cost	$4.80M
Cumulative awarded cost for data set	$824M
Final Cost	
Mean final cost	$1.01M
Median final cost	$637,000
Standard deviation of final cost	$1.03M
Minimum final cost	$32,900
Maximum final cost	$5.26M
Cumulative final cost for data set	$890M
Awarded Schedule	
Mean awarded schedule	300 days
Median awarded schedule	270 days
Standard deviation of awarded schedule	205 days
Minimum awarded schedule	31 days
Maximum awarded schedule	1200 days
Final Schedule	
Mean final schedule	434 days
Median final schedule	366 days
Standard deviation of final schedule	315 days
Minimum final schedule	30 days
Maximum final schedule	1788 days

Issue Log

The data used in the study was extracted from the issue logs from 881 small building projects delivered in 19 public institutions from the U.S. and Canada. In each project in the data sample, an issue log was submitted by the contractor's project team on a weekly basis and then was finalized upon project completion. The issue log was maintained by the contractor's project team in guidance with PMI recommendation, where the project team was responsible to log the list of issues that the project team encountered during construction, the entity responsible for the issue, when the issues were identified and resolved, and the impacts on project cost and schedule (if any). An issue log was typically the first item a project team reviewed during its weekly meeting. During the meeting, the log is updated to document progress on active issues, to indicate when other issues were resolved and what their cost and schedule impacts were, and to document new issues. Furthermore, the issue log also contained the original contracted cost and schedule duration along with the approved final values of project cost and schedule duration.

Definitions of Variables

Issue Types: The issue types used in this study were based on the literature review. Issue types were reported by project participants on a weekly basis throughout the duration of the project, wherein the contractor's project manager would submit a weekly update to the issue log and be responsible for coding the issue types. The owner's construction manager, would then review, suggest modifications, and grant approval to the weekly update (and subsequently the project close out documentation upon completion). The owner's construction manager was a full-time construction professional responsible for day-to-day site and project operations, which lends credibility to the data's accuracy given their high level of involvement in the project activities. The project close out documentation was also typically reviewed by the owner's procurement representative to verify accuracy with contract change requests.

Issue Management: Issue management is the overall management of an issue; from the time it is encountered by the project team until the time it is resolved. In this study, issue management was divided into three categories, which were used as the three dependent variables in the study. These variables, which were used as continuous variables in the analysis, are described below.

Issue Identification: Issue identification is the point during the project that the project team identified the issue and documented it in the issue log. The issue identification was calculated using the following equation:

$$Issue\ Identification = \left(\frac{Issue\ Identification\ Date - Project\ Start\ Date}{Planned\ Duration\ of\ the\ Project}\right)\%$$

Issue Resolution: The issue resolution is the point during the project that the project team resolved the issue and documented the resolution in the issue log. The issue resolution was calculated using the following equation:

$$Issue\ Resolution = \left(\frac{Issue\ Resolution\ Date - Project\ Start\ Date}{Planned\ Duration\ of\ the\ Project}\right)\%$$

Issue Monitoring Period: The issue monitoring period is the length in time between when the project team identified and resolved the issue. The issue monitoring period was calculated using the following equation:

$$Issue\ Monitoring\ Period = \left(\frac{Issue\ Resolution\ Date - Issue\ Identification\ Date}{Planned\ Duration\ of\ the\ Project}\right)\%$$

METHOD OF ANALYSIS

The dataset was analyzed to determine when issue types were identified and resolved during the construction phase of small building construction projects. Specifically, inferential testing of group differences was used to determine whether different issue types were identified at different times and resolved in different lengths of time. Further analysis was conducted to analyze which issues the project teams prioritized and which issues had the shortest monitoring periods. The Kruskal-Wallis H test was used as an inferential test, and pairwise comparison was used as a post-hoc test to determine whether there were significant differences between groups. The Kruskal-Wallis H test was employed instead of one-way ANOVA because the data were not normally distributed and had outliers, thereby violating the two primary assumptions of one-way ANOVA. In contrast, all the assumptions of the Kruskal-Wallis H test were satisfied. The data had independence of observation, meaning there was no relationship between the observations in each independent variable group (issue type) or between the groups. Further, visual inspection of a box plot indicated that all categorical variables were similar in shape.

All three hypotheses stated were tested using the Kruskal-Wallis H test. The variables used in each hypothesis test are provided below.

H1: The eight issue types (categorical variable) were tested for different frequencies of occurrence, which were measured on a per project basis (continuous variable).

H2: The eight issue types (categorical variable) were tested for different Issue Identification and Issue Resolution points in the planned project schedule (continuous variable)

H3: The eight issue types (categorical variable) were tested for different Issue Monitoring Periods, which were measured as percent durations of the planned schedule (continuous variable).

RESULTS

Frequency of Occurrence for Various Issue Types

The analysis shows that some issue types were more prevalent during the construction phase than were other types. As shown in Table 2, the projects in the dataset encountered an average of six issues during the construction phase (based on the summation of mean values for all eight issue types). The results of the Kruskal-Wallis H test indicate statistically significant differences in the frequency of the eight issues types ($\chi^2 = 751.71, p = 0.000$).

Table 2. Descriptive Analysis of the Occurrence Frequency of Issue Types per Project

Issue Type	Mean	Median	Std. Dev.	Minimum	Maximum
OI	1.53	1.00	2.667	0	28
OSC	1.51	0.00	4.129	0	82
DEO	1.02	0.00	5.152	0	80
CPC	0.53	0.00	1.436	0	14
CSS	0.23	0.00	0.727	0	8
UCC	0.49	0.00	1.487	0	21
UWC	0.14	0.00	0.623	0	11
UO	0.48	0.00	1.153	0	10

Further analysis was conducted to determine where the differences were among the issue types. The results of the post-hoc test using pairwise comparison (see Table 3) show several statistically significant differences between issue type frequency. The following results are reported as mean values of each issue type's occurrence on a per project basis. As shown in Table 3, two owner-related issues occurred most frequently, OI (mean: 1.53 times per project) and OSC (mean: 1.51). The second most frequent issue type was DEO (mean: 1.02), followed by CPC (mean: 0.53), UCC (mean: 0.49), and UO (mean: 0.48). The least frequent issue types were CSS (mean: 0.23) and UWC (mean: 0.14). These results indicate that some issue types occur much more frequently than other types. For example, OI and OSC issues occurred approximately ten times more frequently during the construction phase than did UWC issues.

Table 3. Post-Hoc Test for the Occurrence of Issue Types per Project

Base Issue Type	Mean	Comparison Issue Type	Mean	Test Statistic	*p* value
OI	1.53	UWC	0.14	1649.573	0.000*
OI	1.53	CSS	0.23	1476.958	0.000*
OI	1.53	UCC	0.49	1195.658	0.000*
OI	1.53	DEO	1.02	1127.108	0.000*
OI	1.53	CPC	0.53	1061.664	0.000*
OI	1.53	UO	0.48	1056.006	0.000*
OI	1.53	OSC	1.51	325.719	0.000*
OSC	1.51	UWC	0.14	1323.854	0.000*
OSC	1.51	CSS	0.23	1151.240	0.000*
OSC	1.51	UCC	0.49	869.939	0.000*
OSC	1.51	DEO	1.02	801.390	0.000*
OSC	1.51	CPC	0.53	735.946	0.000*
OSC	1.51	UO	0.48	730.288	0.000*
DEO	1.02	UWC	0.14	522.464	0.000*
DEO	1.02	CSS	0.23	349.850	0.000*
CPC	0.53	UWC	0.14	587.909	0.000*
CPC	0.53	CSS	0.23	415.294	0.000*
UCC	0.49	UWC	0.14	453.915	0.000*
UCC	0.49	CSS	0.23	-281.300	0.000*
UO	0.48	UWC	0.14	-593.566	0.000*
UO	0.48	CSS	0.23	-420.952	0.000*

Note: $*p < .05$

Issue Identification and Resolution

In general, project teams identified issues fairly late in a project's planned schedule. Table 4 shows descriptive statistics regarding issue identification, resolution, and monitoring. Half of the issues in the dataset were identified after 70% of the planned project duration had passed. Two time period within the construction schedule–at 55-60% and 90-85% of the planned project duration–were found to have the maximum frequency of issue identification. Cumulatively, 15% of all issues were identified during these two periods. Furthermore, 25% of issues were not identified until after the project's planned completion date; this finding indicates that many projects were delayed and continued to experience issues beyond the initially planned completion date.

Regarding issue resolution, nearly half of the issues were resolved after 85% of the planned project duration had passed. The periods in which issue resolution was most frequent were at 70–75% and 95–100% of the planned project duration. Combined, 15% of all issues were resolved during these issues. Only 60% of the issues were resolved within the planned schedule duration and the remaining 40% of issues were resolved beyond the initially planned completion date.

Table 4. Descriptive Statistics Regarding Issue Management

Issue Management	N	Mean	Median	Std. Dev.	Minimum	Maximum
Issue Identification	4,760	82.40%	72.66%	57.32%	0.46%	298.58%
Issue Resolution	4,760	94.66%	85.90%	57.55%	0.94%	298.78%
Issue Monitoring Period	4,760	22.85%	10.97%	33.09%	0.01%	291.74%

Table 5 shows descriptive statistics for issue identification and resolution across issue types. Inspection of the table indicates that different issue types had different identification and resolution times. The Kruskal-Wallis H test was conducted to determine whether the issue types had statistically significant differences in identification and resolution times. The results indicate statistically significant group differences for issue identification ($\chi^2 = 54.04$ and $p = 0.000$) and for issue resolution ($\chi^2 = 54.42$ and $p = 0.001$).

Table 5. Descriptive Analysis of Issue Identification and Resolution Across Issue Sources

Issue Type	Number of Issues	Mean	Median	Std. Dev.	Minimum	Maximum
Issue Identification						
OI	1,194	84.10%	70.89%	64.06%	0.46%	298.58%
OSC	1,182	83.83%	74.62%	53.81%	1.46%	295.38%
CPC	439	88.55%	82.54%	62.89%	0.71%	298.37%
CSS	180	99.32%	90.24%	63.01%	2.39%	297.37%
DEO	844	72.82%	66.67%	45.79%	0.51%	295.00%
UCC	394	73.30%	61.72%	52.38%	2.12%	288.93%
UWC	115	78.86%	69.03%	56.57%	1.23%	236.97%
UO	412	88.71%	75.82%	59.73%	2.02%	297.44%
Issue Resolution						
OI	1,194	95.59%	85.19%	62.69%	2.21%	295.87%
OSC	1,182	96.91%	88.98%	55.06%	3.65%	297.06%
CPC	439	97.11%	90.79%	63.33%	2.43%	298.78%
CSS	180	109.79%	102.30%	58.97%	8.96%	282.19%
DEO	844	85.20%	79.37%	46.22%	2.04%	295.00%
UCC	394	87.32%	75.39%	56.71%	4.74%	293.73%
UWC	115	89.03%	82.95%	56.28%	2.43%	245.02%
UO	412	104.81%	93.81%	60.30%	0.94%	298.52%

Issue types that were identified earlier were also typically resolved earlier (in contrast with issue types that were identified later and then resolved later). The post-hoc test using pairwise comparison analysis (see Table 6) identified that some issue types had similarities. UCC and DEO issues were identified earliest and also resolved the earliest. For UCC, the median issue identification and resolution times were 61.72% and 75.39%, respectively. For DEO, the median issue identification and resolution times were 66.67% and 79.37%, respectively. CPC and CSS issues were identified and resolved the latest. For CPC, the median issue identification and resolution times were 82.54% and 90.79%, respectively. For CSS, the median issue identification and resolution times were 90.24% and 102.30%, respectively. In addition, though UO issues had one of the earliest median identification times, it also had a later median resolution time of 93.81%.

Table 6. Post-Hoc Test for Issue Identification and Issue Resolution Across Issue Sources

Base Issue Type	Median	Comparison Issue Type	Median	χ2	*p*-value
Issue Identification					
UCC	61.72%	OSC	74.62%	311.16	0.003*
UCC	61.72%	CPC	82.54%	361.49	0.004*
UCC	61.72%	UO	75.82%	380.32	0.002*
UCC	61.72%	CSS	90.24%	648.04	0.000*
DEO	66.67%	OSC	74.62%	245.81	0.002*
DEO	66.67%	CPC	82.54%	296.13	0.007*
DEO	66.67%	UO	75.82%	314.96	0.004*
DEO	66.67%	CSS	90.24%	582.68	0.000*
UWC	69.03%	CSS	90.24%	530.87	0.034*
OI	70.89%	CSS	90.24%	443.67	0.002*
Issue Resolution					
UCC	75.39%	OSC	88.98%	290.81	0.006*
UCC	75.39%	UO	93.81%	446.38	0.000*
UCC	75.39%	CSS	102.30%	605.17	0.000*
DEO	79.37%	OSC	88.98%	242.16	0.002*
DEO	79.37%	UO	93.81%	397.69	0.000*
DEO	79.37%	CSS	102.30%	556.52	0.000*
UWC	82.95%	CSS	102.30%	549.83	0.021*
OI	85.19%	UO	93.81%	256.59	0.029*
OI	85.19%	CSS	102.30%	415.42	0.005*

Note: *p < .05

Issue Monitoring Period

The results show that the issue types had different monitoring period lengths. As shown in Table 7, the median monitoring period across the entire dataset was roughly 11% of the planned project duration, and 75% of the issues were monitored for 25% or less of the planned project duration. The results of the Kruskal-Wallis H test indicate that issue types have statistically significant differences in monitoring periods ($\chi^2 = 38.59$ and $p = 0.000$).

Table 7. Descriptive Analysis of Issue Monitoring Period of Issues Across Issue Sources

Issue Type	Number of Issues	Mean	Median	Std. Dev.	Minimum	Maximum
OI	1,194	25.14%	11.04%	36.29%	0.03%	286.67%
OSC	1,182	24.46%	12.20%	35.15%	0.02%	291.74%
CPC	439	17.78%	7.36%	27.20%	0.03%	196.88%
CSS	180	22.53%	10.00%	35.78%	0.01%	183.64%
DEO	844	19.33%	10.14%	27.14%	0.01%	208.70%
UCC	394	22.92%	13.10%	30.15%	0.41%	225.98%
UWC	115	16.25%	7.21%	30.64%	0.22%	261.54%
UO	412	25.75%	13.41%	34.20%	0.04%	265.97%

Further analysis was conducted to identify the differences in the lengths of the monitoring periods. According to the results of the post-hoc test using pairwise comparison analysis (see Table 8), UWC (median: 7.21%) and CPC (median: 7.36%) issues were monitored for the shortest durations, whereas OI (median: 11.04%), OSC (median: 12.20%), and UO (median: 13.41%) had the longest monitoring periods. The finding that UO issues had a long monitoring period, was consistent with the previous finding that UO issues were identified relatively early but resolved the latest relative to other issue sources.

Table 8. Pairwise Comparison Issue Monitoring Period Across Issue Sources

Base Issue Type	Median	Comparison Issue Type	Median	$\chi 2$	*p*-value
UWC	7.21%	OSC	12.20%	406.18	0.013*
UWC	7.21%	UCC	13.10%	414.85	0.026*
UWC	7.21%	UO	13.41%	479.05	0.005*
CPC	7.36%	OI	11.04%	251.95	0.013*
CPC	7.36%	OSC	12.20%	318.57	0.000*
CPC	7.36%	UCC	13.10%	327.25	0.005*
CPC	7.36%	UO	13.41%	391.44	0.000*

Note: *p <.05

DISCUSSION

Frequency of Occurrence for Issue Sources

The results of this study show that during the construction phase, each small building project executed by a public institution is likely to encounter an average of six issues that are serious enough to threaten a deviation from the contract. This likelihood is the case even in D-B-B projects, wherein a complete scope of work is available to the project team prior to notice to proceed. Institutions that deliver sizable programs of small building projects are therefore encouraged to prioritize systematic risk management and project control techniques, which can help prepare for and lessen the impact of construction issues.

Different issue types were found to occur with different per project frequencies; therefore, H1 was accepted, such that the eight issue types occur with different frequencies during construction. The most frequently occurring issues were the owner-generated issues of OI (mean: 1.53 occurrences per project) and OSC (mean: 1.51), followed by DEO issues (mean: 1.02). These results are consistent with the findings of Mahat and Adnan (2018), who qualitatively analyzed the major causes of change orders in 17 academic building projects and found that the main causes of change orders were related to owner decision-making, owner scope changes, and design errors. It is notable that projects using the D-B-B method were primarily affected by scope changes and by design errors and omissions. In the issue logs examined in the current study indicate that most OI and OSC issues originated from internal business units and end users. This finding, combined with the high frequency of owner-generated issues, highlights the importance of managing internal business units and end users during the planning and design phases (in the hopes of minimizing impacts that occur during construction activities).

The next most frequent issue types were CPC (mean: 0.53), UCC (mean: 0.49), and UO (mean: 0.48). On average, UCC issues affected projects approximately half of the time. This relatively low frequency is surprising because most of the projects in the study involved renovating older facilities, and such projects would presumably be susceptible to more UCC issues than other types of projects would. It is also notable that CPC issues occurred approximately half of the time. This finding indicates that prime contractors generally performed well. Public institutions may be able to reduce the frequency of CPC issues even further by exploring alternate procurement techniques for ensuring the most highly qualified contractors are selected (Nguyen, Lines, and Tran, 2018).

The least frequently occurring issues were CSS (mean: 0.24) and UWC (mean: 0.18). The low frequency of UWC issues could be due to the majority of projects in the study consisting of renovation work in already-constructed facilities, providing protection from external elements. Construction projects in the horizontal sector are much more prone to weather-related impacts since these projects are exposed to the elements (Apipattanavis et al., 2010). However, in vertical projects, weather-related issues are most prevalent in high-rise buildings; which are affected by the changes in atmospheric conditions as elevation increases (Jung, Park, Lee, and Kim, 2016).

Issue Identification and Resolution

Issue identification and resolution tended to occur late in the project schedule. A possible explanation is that the identification time was defined as the point at which the project team entered an issue in the log. It is possible that at least one project stakeholder was aware of an issue before it was logged. If a stakeholder was aware of the issue before documenting it, the stakeholder may have chosen to withhold information about the issue in hopes that it could be resolved before other stakeholders found out. Although not an ideal response, researchers have attributed the lack of communication between stakeholders to be one of the leading factors causing deviations in baseline performance metrics (Gunduz et al., 2013). Moreover, Shohet and Frydman (2003) concluded that half of all communication between stakeholders is informal verbal communication and is not documented. Initially withholding information from other stakeholders may be a symptom of the adversarial relationship that can arise from the D-B-B delivery method (Farnsworth, Warr, Weidman, and Hutchings, 2016).

Different issues types were found to be identified and resolved at different points in the planned project schedule, which led to the acceptance of H2, that the eight issue types are identified and resolved at different points of time during the construction phase. UCC and DEO (median: 66.67%) were identified the earliest (medians: 61.72% and 66.67%, respectively) and were also resolved the earliest (medians: 75.39% and 79.37%, respectively). It is not surprising that UCC issues were identified the earliest, considering that the majority of the projects were renovations of old buildings (some as old as 120 years) and that workers would likely find concealed substances such as asbestos and lead in roofs, floors, walls early on. UCC issues can be identified even earlier if a predesign assessment of the facility is completed (Lo, Ivan, and Karen, 2006).

Although DEO issues are identified the second earliest, identifying them even earlier is possible and can prevent project cost growth. Lopez and Love (2012) estimated that the direct and indirect costs of design errors are 6.9% and 7.4%, respectively. Erikson (2017) noted that many contractors are aware of design discrepancies during the bidding period—long before construction begins—but do not inform the owner of the discrepancies because, if awarded the project, the contractors use the discrepancies as a reason to generate change orders during the project. Owners should strive to reduce design errors and omissions and to encourage contractors to identify such issues during the bidding phase.

The contractor-related issues—CPC and CSS—were identified and resolved later in projects than were other types of issues. This finding may point to contractors' tendency to delay notifying owners about issues, particularly in low-bid projects (Pesek, Smithwick, Saseendran, and Sullivan, 2019). Numerous researchers have pointed out that the construction industry can benefit from improved communication between contractors and owners (Famiyeh, Amoatey, Adaku, and Agbenohevi, 2017).

Issue Monitoring Period

Various issue types had different durations for their Issue Monitoring Period, which led to the acceptance of H3, that the eight issue sources measured in this study will have different monitoring period durations. For example, UWC and CPC issues had shorter monitoring periods (7.21% and 7.36% of the planned project schedule, respectively) than the other issue types had. A possible explanation is that UWC issues can be resolved relatively quickly because technology can predict the length of even the most inclement weather conditions (Shahin, AbouRizk, and Mohamed, 2011). Also, small building projects typically occur within the confines of an existing facility that is fairly protected from external weather conditions when compare to other project types, such as transportation projects that are completely exposed to the elements. Regarding CPC issues, one possible explanation for the rapid resolution time is that contractors typically want to create positive relationships with their clients, perhaps with the goal of receiving future work.

Although OSC and UCC issues were identified the earliest, they had longer monitoring periods than some of the other issue types had. One potential reason is that, as Alps and Stack

(2012) found, owner-initiated scope changes during the construction phase require significant time to incorporate into the project plan. Regarding UCC issues, when such issues are encountered but were not initially in the contract, the contractor is often required to promptly notify the owner (Hatem, 1998). This requirement initiates a series of discussions regarding the nature and magnitude of the concealed condition, additional construction activities, and the associated cost and schedule impacts. These discussions and the resulting activities result in a longer time to close the issue (Sun and Meng, 2009).

UO issues had long monitoring periods and were thus resolved relatively late in the project schedule. UO issues are not caused by prime stakeholders but are external factors often considered to be beyond the control of a project team (Enshassi, Al-Najjar, and Kumaraswamy, 2009). Therefore, these issues can be more difficult to plan for and can take longer to resolve (Wang and Yuan, 2017), thus causing a long monitoring period.

CONCLUSIONS AND CONTRIBUTIONS

The purpose of this study was three-fold. This study investigated the frequency of occurrence, the timing of issue identification and resolution for eight issue types, and the corresponding monitoring period of the same issue types. Results showed that the frequency of occurrence could be categorized into three categories, where OI, OSC, and DEO issues were the most frequently occurring issue during construction. Furthermore, the study found that UCC and DEO issues were identified and resolved the earliest, whereas CPC and CSS were identified and resolved the latest. Lastly, UWC and CPC, had the shortest monitoring period, while, OI, OSC, and UO, had the longest monitoring period.

Research Contributions

Issues identified during the construction phase have been qualitatively shown to affect baseline project performance. Before this study, the most comprehensive research on the timing of issues in small building projects was conducted by Perrenoud et al. (2016), which analyzed 229 projects to investigate the impact of issues on project cost and schedule. According to PMI (2017), monitoring and resolving issues is as important as identifying the issues. Yet few if any researchers have analyzed the length of the monitoring period or the time at which an issue is resolved, let alone analyzed whether the times vary by issues type. The objective of this study was to quantify how frequently different issue types occurred, when each issue type was identified and resolved, and the length of the monitoring period for each issue type. The results of the study show that owner- and designer-related issues occur the most frequently. Moreover, different issue types were identified and resolved at different times and had different monitoring-period lengths.

Contribution to the Body of Knowledge

This study contributes to the body of knowledge by conducting empirical analysis of the various issue types that are most common during the construction of small building projects. This study adds to the body of knowledge by identifying the points in a project at which various issue types are both identified and resolved as well as how long the monitoring periods are. Previous studies, such as Perrenoud et al. (2016) only considered issue identification. This study also contributes to the literature by examining a relatively large dataset from a number of institutions in the public vertical construction sector. Research is not as prevalent in this sector, likely in part because projects in this sector are typically smaller than projects in the horizontal and medical construction sectors.

Contribution to Industry Practitioners

Industry practitioners can use the results of this study to gain insight on how to more effectively manage small building construction projects. Using better strategies in projects can have a positive overall effect on a public institution's facilities. The following recommendations are provided based on the results of this study.

- Project teams (which include both owner and contractor team members) should focus management efforts on the most frequently occurring issue types. Better upfront scoping and early contractor involvement can help identify owner- and designer-related issues earlier, thereby minimizing the risk of cost growth and schedule delays (El-Razek, Bassioni, and Mobarak, 2008).
- Public institutions are encouraged to conduct predesign studies to thoroughly understand potential unforeseen conditions. When a predesign study is not feasible, public institutions should work with contractors to develop action plans that can be implemented should hazardous materials be encountered during construction activities. This practice is in line with PMI's (2017) recommendation that project teams establish accurate contingencies to account for unknown conditions. Further, public institutions should incorporate effective procurement strategies. Using qualifications-based evaluation criteria (along with cost criteria) can help in procuring expert contractor teams (Sullivan, Kashiwagi, and Kashiwagi, 2010).
- Project teams should strive to resolve issues as quickly as possible and be conscious of the resources required to do so. On average, six issues occurred in each project. Even if none of the issues impact the cost or schedule, they still require the project team's time and resources, resulting in indirect costs. This is further shown by the length of the monitoring periods

found in this study for various issue types ranging from 16% to 26% of the planned construction schedule, on average. This means that project team resources are likely to devote substantial time and attention to manage each individual issue that occurs during construction.

- Project teams should vigilantly track all the issues that occur in a project. By tracking the issues, the project team can monitor the issues in a formal and effective manner. Moreover, tracking issues adds to a public institution's historical information, which can be examined to identify trends and enable project teams to more accurately plan for the type of issues that are likely to affect their projects and make data-driven decisions to improve project performance.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The data used in this study were limited to vertical D-B-B projects in public institutions, consisting of small building projects. Although issue types used in the study were based on those found in the literature, the fact that the project participants determined the issue types is a limitation as there is potential for the personal bias of the project participants to be captured in the data. Future research could involve replicating this study in other construction sectors (e.g., transportation, infrastructure, medical, or other large capital sectors) and with projects involving other delivery methods (e.g., design-build, construction manager at risk, and integrated project delivery). Additional research could be conducted to examine whether project performance would improve if issue identification and resolution occurred earlier in the project schedule. For example, researchers could examine the extent to which timely issue management is linked with improved project performance in the areas of cost and schedule. And lastly, future research could also test the relationship of the frequency of issues with overall project performance measures such as cost and schedule growth.

CHAPTER 3: ISSUE TYPES AND THEIR IMPACT ON PROJECT COST AND SCHEDULE

INTRODUCTION

Small building projects play an important role in the operation and maintenance of public sector facilities. In the United States, the need for construction efforts to renovate, redevelop, and expand upon existing facilities has been noted in primary and secondary school buildings (ASCE, 2017), university campuses (Isa and Usmen, 2015), and healthcare facilities (Call, Sullivan, and Smithwick, 2018), among others. More than 50 percent of public schools need to upgrade their facilities by way of repairs, renovations, or modernizations, with the estimated cost of these improvements estimated as $4.5M per school according to a report by the National Center for Education Studies (NCES, 2014). In addition to the general aging nature of public facilities, the importance of small building projects is further elevated when the sheer volume and cumulative dollar value they represent is considered. As just a few examples, Perrenoud, Lines, and Sullivan (2014) documented the small building programs from several public institutions including a public school system, which had an annual budget of more than $140M for small buildings projects, as well as a moderately-sized state institution of higher education, which had an annual portfolio of more than 50 small building projects per year with an aggregated total of $130M. Perrenoud, Lines, Savicky, and Sullivan (2017) reviewed the small building projects within a Midwestern university and reported typical volumes to range from 27 to 67 projects and $20M to $94M per year. Although these projects individually represent fairly low dollar values (the average project sizes in the studies cited above ranged from $400K to $950K), their total volume results in portfolios that are quite sizable for public institutions to oversee.

The substantial volume and monetary value of small building projects necessitates that public institutions exercise careful oversight in their delivery. The oversight of such projects typically rests with the institution's construction management group. For different institutions, effective planning, execution, and oversight of small building projects maximizes the tangible improvements that can be delivered throughout an institution; however, the challenge is doing so in the face of limited budgets, time, and resources (Badger and Garvin, 2007). According to Long, Ogunlana, Quang, and Lam (2004), performance within the construction industry can be improved if common problems are identified on past projects, which makes it important to understand the construction phase challenges that most plague small building projects. This is especially critical because the construction groups in various facilities that oversee these kinds of projects faces the further challenge of an aging professional population (Sullivan, Georgoulis, and Lines, 2010). Therefore, there is a need to document the past performance and challenges experienced in small building projects to pass along this knowledge to the next generation of construction managers in these institutions.

Project performance is a widely researched topic in the construction literature, yet previous studies have primarily been conducted in the horizontal sector. Among studies that have exclusively focused on the vertical sector, the emphasis has most commonly been on larger-scale capital projects rather than the smaller-scale repair, renovation, and modernization work of small building projects, which have been neglected due to low project cost associated. However, small building projects occur with a higher frequency in institutions, amassing high cost for construction program. Therefore, to address this gap in the literature, this study collected and analyzed a sample of 881 small building construction projects from 19 public institutions in the United States and Canada. The objective was to analyze project performance of the construction phase in terms of cost and schedule growth. Additionally, the root-cause sources of cost and schedule growth were tabulated in an effort to identify common problems across project size categories. Results of non-parametric inferential statistical tests found cost growth to be inversely proportional to project size (whereas schedule growth was directly proportional) and owner-caused issuess were found to be the most common causes of cost and schedule growth across all project sizes (whereas unforeseen weather conditions were the least common).

LITERATURE REVIEW

The literature review concentrated on past studies of cost and schedule performance in the vertical construction sector. The literature review also sought to document the leading causes of cost and schedule growth in the construction phase.

Cost and Schedule Growth in Construction

Cost and schedule growth are among the most widely used performance metrics in the construction industry (Hale, Shrestha, Gibson, and Migliaccio, 2009). Previous studies have largely focused on analyzing the cost and schedule performance of large horizontal and infrastructure projects in terms of project type (Shdid, Andary, Chowdhury, and Ahmad, 2019), procurement type (El-Wardani, Messner, and Horman, 2006), contract type (Chen, Xia, Jin, Wu, and Hu, 2015), owner type (Carpenter and Bausman, 2016), and delivery type (Antoine, Alleman, and Molenaar, 2019).

Project performance research in the vertical sector is relatively limited, yet previous studies have included large facilities, housing and apartments, healthcare, and educational projects. This study sought to review studies that focused on Design-Bid-Build (D-B-B) since this is how small building projects are most commonly delivered (Carpenter and Bausman, 2016). The research that has examined cost and schedule growth for vertical D-B-B projects is summarized in Table 9. Combined, these studies examined 2,052 projects, with the largest sample size being 326 projects. A meta-analysis of these studies indicates that the average cost growth for the projects in the studies was calculated at 4.5 percent deviation from contract award. The greatest mean cost growth was 15.6 percent and the lowest was negative 4.1 percent (which represents a cost savings). The average schedule growth for the projects in these studies was 14.2 percent. The greatest mean schedule growth was 41.2 percent and the lowest was 1.0%.

Although these studies captured the public vertical sector, they captured wide range of projects that tended to be relatively large in size compared with small building projects. For example, several of these studies have focused on educational institutions. Carpenter and Bausman (2016) and Col Debella and Ries (2006) analyzed new construction of public school and university projects and reported widely varying average cost growth and schedule growth of 1.5% to 4.5%, and 1.3% to 8.1%, respectively. Furthermore, Rojas and Kell (2008) analyzed 273 new construction and renovation school projects and reported an average cost growth of 6.3%. However, these projects were comparatively large with average project cost ranging from $10M to $22M.

Healthcare projects were also analyzed. Uhlik and Eller (1999) analyzed construction of large healthcare facilities in the United States Army and reported average cost growth of 9.0% with a minimum project cost of $3.2M and a maximum of $108M. The scope of these projects was substantially complex and on average had schedule durations of 2 to 6 years.

Other studies analyzed new construction and renovation projects for Military Construction (MILCON) and private commercial and residential projects. Rosner, Thal, and West (2009), Allen (2001), and Pocock, Hyun, Liu, and Kim (1996), analyzed large facilities projects in the United States Army, such as aircraft maintenance, combat training, and operational buildings, and reported an average cost growth and schedule growth of 6.4% to 12.9%, and 18.8% to 41.2%, respectively. These projects varied in cost with minimum of $4.6M and maximum of $277M. Lastly, studies conducted by Park, Lee, Kim, and Kim (2015), Shehu, Endut, Akintoye, and Holt (2014), Williams (2003), and Thomas, Macken, Chung, and Kim (2002) analyzed large commercial and residential projects, ranging from, $10M to $50M , and reported an average cost growth and schedule growth of -4.1% to 7.8%, and 1.0% to 9.8%, respectively.

Table 9. Literature on Cost and Schedule Growth in Vertical D-B-B Projects

Authors	Sample Size of Vertical D-B-B Projects	Reported Cost Growth	Reported Schedule Growth
Shdid et al. (2019)	43	7.4%	—
Asiedu, Frempong, and Alfen (2017)	321	9.6%	—
Carpenter and Bausman (2016)	86	1.5%	8.1%
Park et al. (2015)	13	1.9%	—
Shehu et al. (2014)	291	1.8%	—
Hwang, Liao, and Leonard (2011)	77	4.8%	28.8%
Rosner et al. (2009)	277	6.4%	18.8%
Hale et al. (2009)	39	4.0%	—
Rojas and Kell (2008)	273	6.3%	—
Col Debella and Ries (2006)	94	3.3% to 4.5%	1.3% to 4.7%
Ibbs, Kwak, Ng, and Odabasi (2003)	30	15.6%	8.4%
Williams (2003)	104	7.8%	9.4%
Thomas et al. (2002)	326	-4.1% to -3.0%	1.0% to 9.8%
Allen (2001)	57	10.6%	30.0%
Uhlik and Eller (1999)	8	9.0%	—
Pocock et al. (1996)	7	12.9%	41.2%

Sources of Cost and Schedule Growth in Construction

Research on vertical and horizontal projects has also focused on the sources of cost and schedule growth. Cost and schedule growth represent departure from the originally contracted project cost and schedule duration. Common causes include design errors, weather conditions, and other unforeseen conditions that occur during the construction phase and change not only the cost and schedule but also the quality of a project from the agreed upon contractual baselines (Perrenoud et al., 2014).

Numerous studies have qualitatively identified the most impactful issue types in the construction industry. Such research has measured the impacts using qualitative data from construction industry stakeholders, including owners, designers, contractors, and subcontractors. Table 10 summarizes the research on the most common issue types affecting cost and schedule growth during the construction phase of public vertical projects. The issue types identified as most significant in these studies were utilized in the current study to understand their impact on cost and schedule growth in small building projects.

Table 10. Literature on the Issue Types with the Greatest Impact on Cost and Schedule Growth in Public Vertical Construction

Paper	OI	OSC	CPC	CSS	DEO	UCC	UWC	UO
Shehu et al. (2014)	✓	✓	✓	-	✓	✓	-	✓
Hwang, Zhao, and Ng (2013)	✓	✓	✓	✓	✓	✓	-	-
Love, Davis, Ellis, and Cheung (2010)	✓	✓	✓	-	✓	✓	✓	✓
Sweis, Sweis, Hammad, and Shboul (2008)	✓	✓	✓	✓	✓	✓	✓	✓
El-Razek, Bassioni, and Mobarak (2008)	✓	✓	✓	-	✓	✓	✓	✓
Alaghbari, Razali, Kadir, and Ernawati (2007)	✓	✓	✓	✓	✓	✓	✓	✓
Wiguna and Scott (2006)	-	✓	✓	✓	✓	✓	✓	✓
Assaf and Al-Hejji (2006)	✓	✓	✓	✓	✓	✓	✓	✓
Aibinu and Odeyinka (2006)	✓	✓	✓	✓	✓	✓	✓	✓
Koushki, Al-Rashid, and Kartam (2005)	-	✓	✓	-	-	✓	✓	✓
Odeh and Batteineh (2002)	✓	✓	✓	✓	✓	✓	✓	✓
Al-Momani (2000)	-	✓	✓	-	✓	✓	✓	✓

Note: OI = Owner—Internal; OSC = Owner—Scope Change; CPC = Contractor—Prime Contractor; CSS = Contractor—Subcontractors and Suppliers; DEO = Designer—Errors and Omissions; UCC = Unforeseen—Concealed Conditions; UWC = Unforeseen—Weather Conditions; UO = Unforeseen—Others

Issue types are the cause of a construction issue that may impact the cost and schedule growth. The issue types identified in these studies are defined below based on the literature.

Owner—Internal (OI): These issue types involved actions of the owner's various internal stakeholders, such as the owner's project manager, facilities management group, or internal user groups. The most common of these sources were delays related to the contract documents, owner decision-making, and payment of contractors.

Owner—Scope Change (OSC): These issues involved the owner's changes to the project's contract documents by adding additional work, directing changes from the originally-provided drawings and specifications, or requesting other alternates.

Contractor—Prime Contractor (CPC): These issues were associated with the prime contractor, regardless of whether they identify themselves as a general contractor or specialty contractor (since both are often primes in small building projects). The most common were delays in payment of subcontractors or suppliers, poor coordination of work, the need for re-work, and poor supervision of or poor-quality assurance regarding subcontractors.

Contractor—Subcontractors and Suppliers (CSS): These issues were associated with subcontractors and suppliers under the oversight of the prime contractor. For subcontractors, the most common issues were the need to perform re-work to repair faulty or low quality construction. The most common supplier issues were delays in material delivery, the delivery of incorrect materials, and delivery of defective or poor-quality materials.

Designer—Errors and Omissions (DEO): These issues were associated with errors and omissions in the drawings and construction documents, typically in the form of conflicts between the drawings and specifications, conflicts between different sheets within the drawings, or inconsistent information among design disciplines (such as architectural plans that were not consistent with structure sheets)

Unforeseen—Concealed Conditions (UCC): These issues were associated with the discovery of buried or covered materials. The most commonly identified UCC were the discovery of deficiencies in hidden structures (e.g. structural integrity issues that were uncovered during construction), presence of unexpected structures or features (e.g. subsurface conditions, buried slabs, etc.), discovery of unexpected artifacts (e.g. archeological artifacts), and the presence of hazardous material (e.g. asbestos, lead paint, etc.)

Unforeseen—Weather Conditions (UWC): These issues involved inclement weather conditions. The most common were snowfall, rainfall, high winds, and dust storms that either impacted or completely shut down construction operations for a period of time.

Unforeseen—Other (UO): These issues involved any other unforeseen circumstances in the project that were not clearly covered by the previous issue types. Examples included unexpected changes in the global construction environment (e.g. material or labor shortages), unexpected changes in economic conditions (e.g. inflation, recession, material price escalation, etc.), unexpected changes in governmental policies, and civil or labor unrest (e.g. protests, strikes).

Strategic Planning across an Organization's Project Portfolio

The key to successful program management is effective strategic planning. Strategic planning across all the projects in an organization's portfolio is critical from an organizational point of view, which can optimize resources and harmonize management efforts to produce better project performance outcomes (Thiry, 2015). Strategic planning includes processes to achieve overarching management objectives, and previous research has shown that having an effective strategic plan incorporated into generalized program management framework (i.e. where multiple projects are managed as a program) can yield superior project outcomes (Shields and Wright, 2016). Similar strategic planning can be applied to program portfolios that manages multiple small building construction projects, in order to achieve positive project performance outcomes such as reducing cost and schedule growth.

RESEARCH OBJECTIVES

Point of Departure

Limited research is available on cost and schedule performance for small building construction projects in public institutions. Although numerous studies have analyzed cost and schedule growth for public construction projects, most of these studies focused on large capital projects in the horizontal and infrastructure sector. Relatively few studies have analyzed vertical construction projects, and the studies that have done so were limited by comparatively large projects and sample sizes, with the largest study having a sample size of 326 projects. Little if any research has analyzed small building construction projects in public institutions, perhaps due to low project costs associated. The current study helps fill the gap by analyzing 881 small building projects in the public vertical institutional sector in the United States and Canada.

The most common result of deviations during the construction phase of project are schedule delays and cost overruns. Many studies have identified the most common issue types for large horizontal and vertical projects. While there are fewer studies on small projects, the majority of these studies have utilized qualitative data rather than quantitatively analyzing the relationship between issue types to cost and schedule growth. The current study fills this gap in the research by analyzing empirical data on eight common issue types (as identified in the literature) to determine the impact of these sources on project cost and schedule growth.

Research Questions and Hypotheses

Previous studies have concluded that project performance varies based upon project size in the horizontal sector (Odeck, 2004) and vertical sector (Shehu et al., 2014). With the need to investigate small building projects in particular, the first research question and corresponding hypothesis statement were developed.

Research Question 4: What is the cost and schedule performance of small building construction projects in public institutions?

Hypothesis Statement 4 (H4): Performance of small building projects, as measured by cost and schedule growth, differs according to project size.

Past studies have qualitatively found scope changes, errors in design, and deficient project team decision-making to be most impactful to project performance (Mahat and Adnan, 2018). However, lack of empirical analysis of the impact of different issue types and how these sources effect different project sizes for small building construction projects led to the development of the second research question and corresponding hypotheses.

Research Question 5: Which issue types have the greatest contribution to cost and schedule growth in small building construction projects?

Hypothesis Statement 5 (H5): The eight issue types examined in this study contribute to cost and schedule growth at different rates (e.g., design errors and omissions may result in greater cost or schedule growth than concealed conditions).

Hypothesis Statement 6 (H6): The eight issue types contribute to cost and schedule growth at different rates according to project size. (e.g., design errors and omissions may result in greater cost or schedule growth for a smaller project than for larger projects).

Hypothesis statement 7 was conducted to supplement the results from H6. H7 is as follow,

Hypothesis Statement *7* ***(H7):*** The project sizes does not contribute to cost and schedule growth at different rates for the eight issue types. (e.g., owner internal issues result in a similar cost growth for all projects sizes; small, medium, or large).

RESEARCH METHODOLOGY

Data Collection

The data used in the study was extracted from the project management documents from 881 small building projects delivered by the facilities management groups in 19 public institutions from the U.S. and Canada. A close-out report provided for each project was used to compile cost and schedule growth performance. In each project in the data sample, a close-out report was submitted by the contractor's project team to the owner at the time of project completion. The document contained an itemized list of all issues that occurred on the project, with the corresponding identification and resolution dates as well as the individual cost and schedule impacts. Furthermore, the document also contained the original contracted cost and schedule duration along with the approved final values of project cost and schedule duration.

Projects in the data set were limited to education and healthcare facilities. Educational projects were limited to construction work that occurred in classrooms, dormitories, dining centers, kitchen spaces, offices, and basic teaching and research laboratories. Similarly, healthcare projects in the data set were limited to construction work that occurred in office spaces, common areas, kitchen spaces, dining spaces, shops, and basic laboratory and patient care facilities. The data set did not contain any complex healthcare construction such as operation room or high-level research laboratories; therefore, the scope of construction work in both educational and healthcare projects was held to be fairly similar. All the data used in this study was empirical data from projects that were delivered via D-B-B method. Lastly, these projects were completed in years 2003 to 2015.

The projects utilized in this study were from 19 public institutions across the United States and Canada. These institutions included higher education, primary and secondary education, municipal governments, and the armed forces (see Table 11). Cumulatively, these institutions provided close-out documentation for 881 completed small building projects. These projects had an average awarded cost of $935K and ranged from a minimum of $30K to a maximum of $4.8M. Cumulatively, the total awarded cost for the entire data set was $824M and the cumulative final cost was $890M, representing a total cost impact of $66M. Awarded project schedule durations ranged from 31 days to just over 1,200 days. The average project duration was 300 days.

Table 11. Summary of Data Set

Demographics	Value
Owner Type	
University	236
Armed Forces	594
City/State/Federal	51
Project Type	
Educational	287
Healthcare	594
Year of Completion	
2003 - 2010	739
2011 - 2015	142
Awarded Cost	
Mean awarded cost	$935,000
Median awarded cost	$597,000
Standard deviation of awarded cost	$976,000
Minimum awarded cost	$30,000
Maximum awarded cost	$4.80M
Cumulative awarded cost for data set	$824M
Final Cost	
Mean final cost	$1.0M
Median final cost	$637,000
Standard deviation of final cost	$1.0M
Minimum final cost	$32,900
Maximum final cost	$5.3M
Cumulative final cost for data set	$890M
Awarded Schedule	
Mean awarded schedule	300 days
Median awarded schedule	270 days
Standard deviation of awarded schedule	205 days
Minimum awarded schedule	31 days
Maximum awarded schedule	1200 days
Final Schedule	
Mean final schedule	434 days
Median final schedule	366 days
Standard deviation of final schedule	315 days
Minimum final schedule	30 days
Maximum final schedule	1788 days

Definition of Variables

The following variables were used to measure project performance, project size, and issue types.

Project Performance: In this study, cost and schedule growth were used as project performance metrics.

Cost Growth (CG): CG was calculated on per project basis. CG is the percent difference between the awarded and the final cost of a project, as calculated using the formula below:

$$CG = \left(\frac{Final\ Cost\ of\ the\ Project - Awarded\ Cost\ of\ the\ Project}{Awarded\ Cost\ of\ the\ Project}\right)\%$$

Schedule Growth (SG): SG was calculated on per project basis. SG is the percent difference between the awarded and the final duration of a project, as calculated using the formula below:

$$SG = \left(\frac{Final\ Schedule\ of\ the\ Project - Awarded\ Schedule\ of\ the\ Project}{Awarded\ Schedule\ of\ the\ Project}\right)\%$$

Project Size: Previous studies have found project size to have an impact on the project cost and project schedule for horizontal projects (Odeck, 2004) and vertical projects Shehu et al. (2014). Project size categories for this study were based on a number of previous studies that investigated small building construction programs of public vertical institutional facilities (Hurtado et al. 2017, Hurtado et al. 2018, Perrenoud et al. 2014, Perrenoud et al. 2017). Moreover, the data set contains fairly substantial portion of student housing and short-term living apartments, and Shehu et al. (2014) analyzed over 350 housing and apartment project and used similar project size categories within small building construction projects.

Small (<$375,000): All projects with awarded costs less than $375,000 were categorized as small projects.

Medium ($375,000–$1M): All projects with awarded costs of at least $375,000 but less than $1M were categorized as medium projects.

***Large ($1M–$5M*)**:** All projects with awarded costs of $1M to $5M were categorized as large projects.

Issue types: The issue types used in the study were similar to those identified in the literature review and were treated as a categorical variable when analyzing the data.

METHOD OF ANALYSIS

The study data was analyzed to determine whether projects of different sizes have different cost and schedule growth and to determine how issue types affect cost and schedule growth. Specifically, inferential testing of group differences was used to determine whether cost and schedule growth differed in regard to project size and issue types. The Kruskal-Wallis H test was used as an inferential test. Pairwise comparison was used as a post hoc test to determine whether there were significant differences between groups. The Kruskal-Wallis H test was employed instead of one-way ANOVA because the data were not normally distributed and contained outliers, thereby violating two primary assumptions of one-way ANOVA. In contrast, all the assumptions of the Kruskal-Wallis H test were satisfied. The data contained two dependent continuous variables (cost growth and schedule growth) and two independent categorical variables (project size and issue types). Moreover, the data had independence of observation, meaning there was no relationship between the observations in each group of the independent variable or between the groups themselves. Further, visual inspection of the box plot indicated that all categorical variables were similar in shape.

RESULTS

Nearly all projects experienced cost and schedule growth. As shown in Table 12, of the 881 total projects, 832 (94.4%) experienced cost growth and 771 (87.5%) experienced schedule growth. The average cost growth was 8.6%, and the average schedule growth was 44.5%. The median values for cost and schedule growth were 2.3% and 22.2%, respectively. These values were much lower than the averages because both variables displayed a positively skewed distribution.

Table 12. Overall Project Performance of the Sample Size

Variable	N	Mean	Median	Std. Deviation	Minimum	Maximum
Cost Growth (%)	881	8.6%	2.3%	17.7%	-31.6%	189.8%
Schedule Growth (%)	881	44.5%	22.2%	60.4%	-47.9%	301.5%

Performance Differences Based on Project Size

The results of the Kruskal-Wallis H test (see Table 13) indicate there are statistically significant differences in cost and schedule growth for different project sizes (p = 0.05 and 0.001, respectively). Smaller projects experienced greater cost growth than did larger projects. Conversely, larger projects experienced greater schedule growth than did smaller projects.

Table 13. Kruskal-Wallis H Test on Project Performance in Relation to Project Size

Project	Cost Growth (%)					Schedule Growth (%)				
Size	N	Mean	Median	$\chi2$	*p* value	N	Mean	Median	$\chi2$	*p* value
Small	311	10.7%	3.5%			245	36.6%	12.8%		
Medium	245	7.5%	1.5%	5.9	0.05*	290	46.5%	24.9%	13.7	0.00*
Large	276	7.7%	2.2%			236	50.1%	30.2%		

Note: * p <.05.

Impact of Issue types on Project Performance

Results of the Kruskal-Wallis H test (see Table 14 and 15) indicate there is a statistically significant difference in the cost and schedule growth resulting from different issue types (p = 0.00 for each cost and schedule growth test results, respectively). Post hoc analysis using pairwise comparison was conducted to determine which issue types affected the cost and schedule the most. The analysis results indicate that OSC, DEO, and UCC caused the highest cost growth (p = 0.00). For schedule growth, OI and OSC caused the highest schedule growth. Further testing showed that within each project-size category OSC, DEO, and UCC had the highest cost growth, while OI and OSC resulted in the greatest schedule growth. These results indicate that the performance of small building construction projects is affected by issue types.

Table 14. Kruskal-Wallis H Test on Project Performance in Relation to Issue Types for Cost Growth

Issue Type	N	Mean	Median	Max.	Min.	χ2	*p* value
OI	471	3.60%	0.00%	49.30%	-13.30%	413.5	0.00*
OSC	395	8.30%	2.80%	48.00%	-15.20%		
CPC	229	0.60%	0.00%	37.20%	-8.00%		
CSS	124	1.00%	0.00%	12.00%	-4.30%		
DEO	202	3.60%	0.90%	42.70%	-0.90%		
UCC	190	2.90%	0.80%	39.00%	-6.70%		
UWC	80	0.20%	0.00%	4.70%	-0.60%		
UO	232	3.00%	0.00%	43.50%	-13.30%		

Note: * $p < .05$.

Table 15. Kruskal-Wallis H Test on Project Performance in Relation to Issue Types for Schedule Growth

Issue Types	N	Mean	Median	Max.	Min.	χ2	*p* value
OI	446	37.10%	18.60%	98.16%	-49.73%	163.6	0.00*
OSC	373	24.20%	3.60%	93.25%	-42.59%		
CPC	227	11.60%	0.00%	98.92%	-45.06%		
CSS	119	10.90%	0.00%	72.00%	-38.46%		
DEO	196	13.40%	0.00%	97.55%	-33.33%		
UCC	187	8.90%	0.00%	97.64%	-15.63%		
UWC	80	9.60%	0.00%	77.89%	-48.65%		
UO	229	15.80%	0.00%	90.34%	-39.74%		

Note: * $p < .05$.

Variations in Issue types Impacts in Relation to Project Size

Results of the Kruskal-Wallis H test (see Table 16) indicated that, for all project sizes, issue types had statistically significant differences in the impact on cost and schedule growth. Further, these differences varied by project-size category. Post hoc tests were conducted to determine which issue types affected the cost and schedule growth the most for project within a specific size category. The results show that irrespective of size, OSC, DEO, and UCC were associated with the highest cost growth, whereas OI and OSC were associated with the highest schedule growth.

Table 16. Kruskal-Wallis H Test on Project Performance in Relation to Issue types and Project Size

Project Size	Issue types	Cost Growth (%) N	Mean	Median	χ2	*p* value	Schedule Growth (%) N	Mean	Median	χ2	*p* value
Small	OI	130	5.1%	0.0%	133.5	0.00*	116	36.0%	15.2%	58.6	0.00*
	OSC	148	11.0%	4.0%			135	24.0%	3.9%		
	CPC	32	0.0%	0.0%			32	-1.1%	0.0%		
	CSS	44	0.3%	0.0%			42	16.8%	0.0%		
	DEO	76	4.5%	1.3%			74	18.0%	0.0%		
	UCC	52	3.2%	1.7%			51	13.7%	0.0%		
	UWC	18	0.6%	0.0%			18	12.4%	0.0%		
	UO	37	3.2%	0.0%			37	9.5%	0.0%		
Medium	OI	161	3.1%	0.0%	125.1	0.00*	153	40.9%	24.4%	72.5	0.00*
	OSC	108	7.8%	2.3%			101	28.2%	2.0%		
	CPC	92	1.2%	0.0%			90	14.8%	0.0%		
	CSS	40	0.2%	0.0%			37	8.6%	0.0%		
	DEO	57	5.1%	0.7%			54	13.3%	0.0%		
	UCC	59	4.1%	1.0%			58	6.9%	0.0%		
	UWC	16	0.1%	0.0%			16	0.9%	0.0%		
	UO	82	3.7%	0.0%			79	21.6%	4.6%		
Large	OI	144	3.1%	0.0%	125.0	0.00*	141	39.7%	21.3%	66.0	0.00*
	OSC	112	6.5%	1.9%			110	22.5%	4.2%		
	CPC	79	0.4%	0.0%			79	8.1%	0.0%		
	CSS	31	3.2%	0.0%			31	7.6%	0.0%		
	DEO	55	1.8%	0.9%			54	9.8%	0.0%		
	UCC	65	2.1%	0.6%			64	8.1%	0.0%		
	UWC	35	0.1%	0.0%			35	13.3%	0.0%		
	UO	90	2.7%	0.0%			90	15.4%	2.8%		

Note: * $p < .05$.

When each issue types was analyzed separately, cost and schedule growth were still affected in a similar way regardless of project size. Table 17 shows the results from the inferential test conducted. Only one category—schedule growth with CPC—had statistically significant results. However, closer inspection revealed that all the median values were zero and, therefore, the differences were non-significant. Every other category was found to be non-significant, suggesting that each issue types affects small building construction projects a similar way regardless of project size. In other words, each issue types had the same cost and schedule growth rates regardless of project size. These findings support the previously discussed results that irrespective of size, OI, OSC, DEO, and UCC have the greatest impact on cost and schedule growth.

Table 17. Kruskal-Wallis H Test on Issue types and Project Size in Relation to Project Performance

Issue Type	Project Size	Cost Growth (%) N	Mean	Median	χ2	*p* value	Schedule Growth (%) N	Mean	Median	χ2	*p* value
	Small	130	5.1%	0.0%			116	36.0%	15.2%		
OI	Medium	161	3.1%	0.0%	2.1	0.35	153	41.0%	24.4%	2.9	0.24
	Large	144	3.1%	0.0%			141	39.7%	21.3%		
	Small	148	11.0%	4.0%			135	24.0%	2.0%		
OSC	Medium	108	7.8%	2.3%	6.0	0.05	101	28.2%	4.2%	0.1	0.96
	Large	112	6.5%	1.9%			110	22.5%	15.2%		
	Small	32	0.0%	0.0%			32	-1.1%	0.0%		
CPC	Medium	92	1.2%	0.0%	0.1	0.97	90	14.8%	0.0%	8.6	0.01*
	Large	79	0.4%	0.0%			79	8.1%	0.0%		
	Small	44	0.3%	0.0%			42	16.8%	0.0%		
CSS	Medium	40	0.2%	0.0%	3.3	0.19	37	8.6%	0.0%	2.7	0.26
	Large	31	3.2%	0.0%			31	7.6%	0.0%		
	Small	76	4.5%	1.3%			74	18.0%	0.0%		
DEO	Medium	57	5.1%	0.7%	1.8	0.40	54	13.3%	0.0%	0.5	0.77
	Large	55	1.8%	0.9%			54	9.8%	0.0%		
	Small	52	3.2%	1.7%			51	13.7%	0.0%		
UCC	Medium	59	4.1%	1.0%	3.1	0.21	58	6.9%	0.0%	0.6	0.72
	Large	65	2.1%	0.6%			64	8.1%	0.0%		
	Small	18	0.6%	0.0%			18	12.4%	0.0%		
UWC	Medium	16	0.1%	0.0%	0.4	0.83	16	0.9%	0.0%	2.2	0.34
	Large	35	0.1%	0.0%			35	13.3%	0.0%		
	Small	37	3.2%	0.0%			37	9.5%	0.0%		
UO	Medium	82	3.7%	0.0%	0.6	0.75	79	21.6%	4.6%	3.2	0.12
	Large	90	2.7%	0.0%			90	15.4%	2.8%		

Note: * $p < .05$.

DISCUSSION

Performance Differences Based on Project Size

The analysis indicated that project performance of small building construction projects in public institutions varies according to project size; therefore, H4 was accepted. As shown in Table 13, small projects had greater cost growth (median = 3.5%) than did medium and large projects, which had median cost growth of 1.5% and 2.2%, respectively. Conversely, large projects had greater schedule growth (median = 30.2%) than did medium and small projects, which had a median schedule growth of 24.9% and 12.2%, respectively. The implication is that all small building construction projects in an institution's portfolio are prone to experience cost or schedule growth. That said, large projects are still affected by higher cost growth in terms of raw magnitude, where large projects incur $50,000 median cost growth compared to $2,000 for small projects. Similarly, for schedule growth, large projects incur median schedule growth of 120 days as compared to 14 days for small projects, hence, these results emphasize the importance of establishing effective oversight practices and strategic planning for all construction projects in an institution's construction program.

Although the cost growth for an individual project may not be large, the cumulative impact of cost growth across an institution's entire portfolio may be substantial. For example, public institutions may deliver anywhere from several dozen to more than 100 small building projects during a year, with total annual construction values of $130M to more than $325M (Perrenoud et al., 2014). If an institution with an annual portfolio of small building projects valued at $130M experienced the 8.6% mean cost-growth rate identified in this study, the cumulative project cost growth would be more than $10M (every year!). Therefore, the cost-performance implications are significant enough to warrant close scrutiny in an institution's budgeting, planning, and management processes.

Similar implications can be inferred regarding schedule growth. For public institutions—especially schools and medical facilities—schedule growth in any construction project can have a considerable impact. This is because the institution's core business functions may be hampered when a new or renovated space is not ready for use by the originally planned date. This study found that large projects had a median schedule delay of 120 days, which equates to nearly an entire school semester. Imagine an institution's frustration when the construction deadline for a classroom, laboratory, or student-housing project is extended by 120 days. Such a lengthy delay could jeopardize the institution's instructional performance, accreditation status, or ability to conduct research. Such a delay could also require the institution to incur a sizable cost if off-campus accommodations must be provided for an entire semester to substitute for lost student-housing space.

Impact of Issue Types on Project Performance

Four of the eight issue types examined in this study (OI, OSC, DEO, and UCC) had greater impacts on cost and schedule growth than did the other issue types; therefore, H5 was accepted. As shown in Table 14, more specifically, OSC, DEO, and UCC were associated with a significantly higher cost growth than were the other issue types. Further as shown in Table 15, owner-related issue types (OI and OSC) were associated with a significantly higher schedule growth than were the other issue types. The remaining four issue types (CGSI, CSS, UWC, and UO) had significantly lower associations with both cost and schedule growth.

Unsurprisingly, UCC were among the largest causes of cost growth. This relationship is likely inherent in small building projects since the construction activities largely occur in facilities that are aging and may have been repurposed several times previously, leading to a greater likelihood that unforeseen conditions will affect future projects. A review of records from the projects in this study indicates that common UCC include the presence of hazardous materials (e.g., asbestos and lead) in older facilities, the presence or absence of structural materials that were not found until demolitions were conducted (e.g., until a wall or ceiling was removed during construction to expose the underlying structure), and subsurface conditions (under floors, basements, and surrounding areas outside the building footprint).

At first glance, it may be surprising that OI, OSC, and DEO had major adverse effects on project performance, since all projects in this study were delivered via D-B-B delivery. In D-B-B, the construction documents are traditionally assumed to be 100 percent complete before the construction phase begins. Yet the high rates of OI, OSC, and DEO prove that the original construction documents were inadequate for completing the construction phase without affecting the budget or completion deadline. Unfortunately, since these issue types are not being uncovered until the construction phase, the institution has little choice but to increase the project cost and schedule in order to accommodate the changes. This result points to challenges during the planning stages of small building projects within the institution's facilities management group or the design professionals they partner with. The challenges may even be symptomatic of a silo effect; for example, institutions may assign responsibility for project planning (producing the construction documents) and construction delivery (building the construction documents) to different workgroups. In this case, the institution has established a division in responsibility for planning and construction, which can lead to a communication breakdown between the workgroups and can increase the likelihood of cost and schedule growth during the construction phase.

An encouraging implication of this study is that OI, OSC, DEO—three of the four highest-impact issue types—can be largely planned for and controlled by the institution's internal management practices. For example, the prevalence of OI, OSC, and DEO indicate that the majority of cost and schedule growth is the result of challenges during the planning stages of the project. Institutions can respond by improving their planning procedures and bolstering the linkage between the planning and construction phases.

Variations in Issue types Impacts on Different Project Size

Each of the eight issue types influenced project performance in a different way for each project size, however, they affected every project size in a similar pattern; therefore, H6 was accepted. For example, as shown in Table 16, OSC, DEO, and UCC caused significantly higher cost growth for all three project-size categories compared to the other issue types. Similarly, OI and

OSC caused significantly higher schedule growth for all three project sizes. Further analysis, as shown in Table 17, also indicates that each issue types tended to contribute to cost and schedule growth at a similar rate regardless of project size, therefore H7 was also accepted. As one example, OI had median cost growth rates of 3 to 5 percent and median schedule growth rates of 15 to 24 percent across all three size categories. Industry practitioners can use this information to focus their management efforts on the issue types with the greatest impact on cost and schedule growth (OSC, OI, DEO, and UCC), thereby improving performance across an institution's entire portfolio of small building projects, regardless of a specific project's size.

CONCLUSIONS AND CONTRIBUTIONS

One objective of this study was to better understand construction project performance for small building construction projects in public institutions. This objective was achieved by collecting data on 881 construction projects in 19 public institutions. Another objective of the study was to understand the effect of issue types on cost and schedule growth of small building construction projects in these institutions. The study data were analyzed to identify which issue types caused the greatest cost and schedule growth and to determine whether these issue types had different affects based on project size.

The results show that construction projects of all sizes were plagued by cost and schedule growth. Small projects tended to have the greatest cost growth, whereas large projects tended to have the greatest schedule growth. Four issue types (OSC, OI, DEO, and UCC) were found to account for the vast majority of project performance growth. The effect of each issue types on project performance remained relatively consistent across the project-size categories.

Contribution to the Body of Knowledge

This study adds to the body of knowledge by providing the largest empirical dataset to-date for small building projects in public institutions. Previous research on project performance has primarily focused on horizontal projects, such as highways, roadways, bridges, and other transportation projects (Antoine et al., 2019; Chen et al., 2015; El-Wardani et al., 2006). In the vertical sector, previous research has mainly focused on new projects, megaprojects (Shdid et al., 2019), medical facility projects (Call et al., 2018), and other large-scale projects (Asiedu et al., 2017; Rosner et al., 2009; Thomas et al., 2002).

Contribution to Industry Practitioners

The results of this study can help industry practitioners create a strategic plan for small building construction programs. For example, construction teams can potentially greatly improve performance across an institution’s small building projects by focusing on program-wide strategies to minimize OSC, OI, DEO, and UCC. Specific recommendations regarding these issue types include the following:

- Construction teams are encouraged to systematically track the rates of OSC in their projects. Doing so may identify internal user groups that typically have higher rates of scope change, and this information will enable facility managers to more proactively manage these groups during the project planning phase and thereby avoid negative effects on productivity. As a more extreme strategy, an institution’s budgeting processes could be modified to “charge” user groups with higher internal costs, which could discourage user groups from making changes after the planning phase.
- Similarly, quantitative measurement of DEO can provide institutions with greater leverage when negotiating with external design consultants. For example, with DEO data

an institution can be better positioned to hold design professionals accountable for errors that cause cost and schedule growth during the construction phase. An institution can also use the information to identify the most commonly encountered errors and omissions that plague their small building projects.

- This study's results show that OI cost and schedule growth most commonly stemmed from inadequately prepared resources in an institution's internal user group (e.g., the department or work group that will occupy the space was not sufficiently prepared to contribute timely decisions, reviews, and approvals). Therefore, practitioners are encouraged to proactively engage internal user groups in order to better prepare them to execute construction phase activities in a timely and cost-effective manner.
- The substantial cost and schedule growth across small building project portfolios necessitate a proactive management approach. Because individual issue types tend to affect cost and schedule growth at similar rates regardless of project size, practitioners should implement a systematic approach to addressing issue types across an institution's entire portfolio. Doing so could pay off in great dividends.
- Since certain issue types account for the vast majority of cost and schedule growth, facility managers should consider altering their procurement procedures to take these factors into account. For example, best-value procurement enables institutions to review contractors' risk management skills, past performance on similar projects, and project team capabilities. Perrenoud et al. (2017) found these traits to be linked with higher client satisfaction upon project completion. Using the best-value method would enable institutions to systematically select contractor teams that are well-suited to avoid the issue types historically shown to have the greatest impact on project performance.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The results of this study provide insight into the performance of small building construction projects in public institutions, but this study includes several limitations. For example, though this study analyzed a large sample of projects, most were education and healthcare projects and may not be applicable to other facility types. Further, all the projects were limited to D-B-B projects and therefore cannot be generalized to other delivery methods such as Design-Build (D-B), Construction Manager at Risk (CMAR), or Integrated Project Delivery (IPD). Lastly, the results of the study only depict the issue types encountered and the performance of small building projects in the United States and Canada. Future research could be conducted to examine other project types (e.g., horizontal, infrastructure, other vertical facility types), other delivery methods (e.g., Design-Build, Construction Manager at Risk, Integrated Project Delivery), and other project sizes. Future research could also analyze when different issues are encountered or resolved and how the timing affects the cost and schedule growth of a project.

CHAPTER 4: THE EXTENT OF PROJECT TEAM UTILIZATION OF ISSUE MANAGEMENT

INTRODUCTION

Construction projects are challenging to execute and require the diligent application of project control techniques (Alinaitwe *et al.,* 2013). Project control can be defined as the data monitoring, management, and analytical processes used to understand and constructively inform decisions that may impact the performance outcomes of a project (Orgut *et al.,* 2020). Due to their importance, numerous project control techniques have been developed to assist project teams. For example, the Project Management Body of Knowledge (PMBoK), which is among the most well-known resources in the field of professional project management, advocates the usage of numerous project control techniques (PMI, 2017; Martens and Vanhouke, 2018). Among these are techniques such as Earned Value (EV), the Critical Path Method (CPM) of scheduling, root cause analysis, trend analysis, variance analysis, To-Complete Performance Index (TCPI), inspections related to scope, quality, and safety, the Program Evaluation and Review Technique (PERT), and Risks Assumptions Issues and Dependencies (RAID) logs, to name only a few (PMI, 2017). Many, if not all, of these techniques see widespread application in the construction industry.

Issue management is a project control technique of paramount importance given that construction projects are beset by such a wide range of issues. Issues are defined as challenges that occur during project execution which threaten to cause a deviation in the project's originally contracted cost, schedule, or scope (PMI, 2017). Issues therefore require an active management response by the construction team. The PMBoK recognizes that the extent to which issue management is practiced by project teams can reduce negative impacts and improve project performance and recommends the use of issue log for issue management (PMI, 2017). However, limited studies in the construction literature have analyzed the extent to which issue logs are implemented in the construction phase and the corresponding link to project performance outcomes. Dikmen *et al.* (2018) noted that existing studies in this area tend to focus on risk management, which can be interchangeable with issue management when studies focus on risk events that occur during construction (e.g. such risks are issues by definition). Their study found that a “large number of studies in the construction management domain” tend to utilize rely on “subjective risk ratings” by multiple experts, which ultimately generate results that “may be inconsistent/biased due to different perspectives and controllability assumptions” included in such rating schemas. Their study concluded by recommending future studies be designed to “de-bias” possible inconsistencies that can arise by gathering risk (and/or issue) data via methods that accurately reflect project team consensus. One method for accomplishing this is to capture project documents – such as issue logs – which are empirical records that represent the consensus of the entire project team.

Past studies have also emphasized the importance of issue logs within the broader domain of project control. For example, Tereso *et al.* (2019) surveyed several chapters of the Project Management Institute (PMI) and identified issue logs as being among the top 15 most used project control tools out of a list of 79 tools and techniques recommended by the PMBoK. Furthermore, the study found issue logs to be the top-ranked tool in the ‘project execution’ phase of projects. Golini *et al.* (2015) gathered data from nearly 500 project managers to assess the impact of project management practices on project performance and found that project managers who adopt a wider range of tools are more likely to achieve higher performance results. Their study revealed four levels of maturity in the adoption of PM tools, wherein the usage of issue logs was associated with the highest level of maturity. These studies underscore the importance of issue logs in the project management profession, which warrants additional investigation into the specific usage of issue logs in construction and corresponding impact on project performance.

Previous literature has identified several gaps in the study of issue logs. First, previous studies (e.g. Dikmen *et al.* 2018) suggest that issue management studies should expand beyond the qualitative measures that are prominent in the literature and also be de-biased by designing research methods that ensure the perspective of the entire project team is captured (rather than only a single individual on the project team). Second, previous studies (e.g. Golini *et al.* 2015; Tereso *et al.* 2019) have noted the prominence of issue logs as a widely-used project management tool; however, such studies stopped short of studying the extent to which issue logs are used by project teams and the corresponding relationship with construction project performance. Future studies can address these gaps by utilizing data from issue logs for several reasons: first, issue logs represent empirical and quantitative documentation of the issues that occur during construction; second, issue logs are a shared document approved by the entire project team, which necessitates that it represents the team's consensus rather than the opinion of individual stakeholders; and third, issue logs typically contain information related to the timing, cost impacts, and schedule consequences of individual issues, all of which illuminates the extent to which construction teams utilized issue logs. Therefore, further investigation of issue logs is warranted in the construction literature.

This study aims to investigate two research objectives on the topic of issue logs within the context of construction projects. The first research objective was to investigate whether project teams who utilize issue logs to a greater extent tend to achieve more successful project performance outcomes. The second research objective was to determine extent to which project teams practice consistent (or variable) issue log implementation throughout the project's construction phase. Existing literature has not focused on the extent nor consistency with which project teams implement issue logs during construction. If greater and more consistent issue log implementation is found to correspond with superior project performance, it may be motivating for practitioners to place strong emphasis on this project control tool.

LITERATURE REVIEW

The literature review is organized into several subsections. First, previous research on the relationship between project control and project performance is discussed. Next, change order management and issue management are both reviewed within the context of the construction literature. Finally, the usage of an issue log as an effective project control technique is reviewed in accordance with recommendations of the PMBoK and studies within the construction literature.

Relationship between Project Control and Project Performance

Previous studies have shown the extent to which project teams exercise project control is associated with improvements in project performance. Past research has defined effective project control in terms of prompt identification of issues and early stakeholder involvement and have qualitatively shown that these might help lessen the impact of cost and schedule growth during construction (Braimah, 2014; Santoso and Soeng, 2016). However, simply implementing and utilizing project control tools to manage issues is not enough to ensure project does not incur negative performance outcomes (Olawale and Sun, 2010). Rather, Safapour and Kermanshachi (2018) demonstrated that using best practices in project control have the greatest potential to improve project performance, yet performance improvements are largely dependent upon the extent to which best practices are adhered to by project teams.

Change Order Management

One important aspect of project control is the management of change orders. Change orders represent deviations from the originally contracted cost or schedule. The accumulation of all change orders that occurred during the project is equivalent to the overall project cost and schedule growth. Numerous studies have been conducted in the construction literature with respect to how project teams manage change orders. Serag *et al.* (2010) analyzed 16 transportation projects and found that the timing of change orders is directly proportional to their cost growth. Several other studies have found that when change orders were managed later in a project, they have a greater negative effect on labor efficiency (Ibbs, 2005; Moselhi *et al.,* 2005). Shrestha and Maharjan (2018) analyzed 15 transportation projects and Apipattanavis *et al.* (2010) analyzed over 1,900 transportation projects, both studies concluded that as the frequency of change orders increases, cost and schedule growth also increases. Moselhi (2003) analyzed 57 projects of various types and found that the frequency of change orders negatively affects labor productivity. These studies indicate that the manner in which project teams manage change orders associated with project performance in the areas of cost and schedule growth as well as labor productivity.

Issue Management

Issue management is an extension of change order management and offers a different unit of measure that is valuable to research inquiry. Change orders are often comprised of multiple impactful issues that resulted in a deviation to project cost and schedule (Anastasopoulos *et al.,* 2010). Issue management in contrast emphasizes a project team's actions to *prevent* issues from precipitating into change orders in the first place. In this sense, utilizing individual issues as the unit of measure enables documentation of both the impactful issues which precipitate formal change orders as well as "near miss" issues that were addressed by the project team without ultimately impacting project cost or schedule. A similar principle was documented by Sullivan and McDonald (2011), who demonstrated that attention to "near miss" events (in addition to events that directly impacted operational parameters) resulted in greater performance in the context of a manufacturing production system.

Effective implementation of issue management techniques is critical in the construction industry given the wide range and frequency of issue types that may be encountered. Issues may be caused by a variety of factors, including those from owners, designers, contractors, and unforeseen circumstances that occur during construction (Gardezi *et al.,* 2014; Shehu *et al.,* 2014). Previous studies have identified issues in a wide variety of contexts, including in developing countries (Odeh and Battaineh, 2002) and developed countries (Gündüz *et al.,* 2013), public owners (Alaghbari *et al.,* 2007) and private owners (Sambasivan and Soon, 2007), and in horizontal projects (Ellis and Thomas, 2003) and vertical projects (Sweis *et al.,* 2008). However, these studies did not investigate the extent to which issue management was implemented and were often limited to qualitative methods, such as identifying the relative frequency or importance of different issue types via interviews, surveys, or mixed methods (Prasad and Venkatesan, 2017).

Issue Logs as an Effective Tool for Issue Management

Issue logs are considered as one of the essential tools for issue management. The PMBoK recommends the use of an issue log to formalize issue management within a project team's operations (PMI, 2017). Although the PMBoK does not provide a standardized issue log template, it does recommend certain best practices. For example, the issue log is advised to consist of a consistent format that provides an itemized and written record of all potential and actual issues that could impact the project cost and schedule. Certain information about each individual issue should be documented in the issue log, such as the point in the schedule at which the issue was first identified and then subsequently resolved. The project team's management response plan to mitigate the issue should also be recorded in a way that clearly assigns action items. Such information is also useful in a post-project review of lessons learned. Furthermore, Mossalam (2020) defines issue log as a project control tool that is used during the issue management process to monitor and control deviations to the contracted cost and schedule on the project

In addition to the information captured within the issue log, certain aspects of how the log should be used in practice are also recommended by the PMBoK. For example, the issue log should be formalized as part of regular discussions to review the status of each issue (typically during weekly project management meetings). Project teams are advised to develop forecasts of the potential impacts to project cost and schedule for issues that are being actively monitored. Finally, the resulting cost and schedule impacts (if any) should be clearly documented for each individual issue upon resolution. The extent to which project teams utilize these issue log practices is largely unstudied in the construction industry and can be reasonably expected to have a direct relationship with project performance.

The above recommendations from the PMBOK are supported in the construction literature. Golini *et al.* (2015) defined issue logs as a "structured document" which tracks issues that have occurred, monitors who is responsible for resolving specific issues, and addresses issue resolution obstacles. Mossalam (2020) noted that stakeholders can gain visibility into project challenges by monitoring issue logs. Similarly, in a study of quality management programs utilized in construction, Sullivan (2011) noted the importance of a regular tracking system where the contractor was responsible for documenting issues that had the potential to impact project cost, schedule, or scope. The study noted the importance of distributing such information to all parties involved with the project. Perrenoud *et al.* (2016) recommended that construction teams document the timing with which issues are 'encountered' within the project schedule. Kotb and Ghattas (2018) noted issue logs as a primary project document that can provide important information for identifying threats to project performance in the context of construction projects.

RESEARCH OBJECTIVES

Point of Departure

The topic of project control has been broadly investigated in the construction literature, yet relatively little inquiry has focused specifically on the project control tool of issue logs in issue management. To address this gap, this study specifically investigated the usage of issue management practices (in the form of formal issue logs) by project teams during the construction phase of their projects.

The unit of measure used in this study represented a departure from previous research. In this study, the primary unit of measure was focused on capturing the individual issues that occur during the construction phase. Although individual issues may or may not ultimately impact the project's cost, schedule, or scope, their occurrence nevertheless necessitates a management response from the project team. Therefore, capturing critical information on the occurrence of each individual issue, the corresponding management response from the project team, and subsequent impacts to project cost and schedule are important in quantifying the effectiveness of issue management as a project control tool. Previous studies have tended to use individual change orders as a unit of measure. One limitation of change orders as a unit of measure is that they are often comprised of multiple underlying issues, which makes it difficult for researchers to apportion the resultant cost and schedule changes to their specific root cause issues. Another limitation is that change orders only include the issues that resulted in a change to project cost and schedule; therefore, change orders to not account for other “near miss” issues that were managed by the project team in such a way that the potential cost and schedule impacts were successfully eliminated. Thus, using individual issues as the unit of measure provides a more granular view of the challenges that are managed by the project team during construction.

Among studies that have touched on issue management in construction, their research designs have predominantly been limited to qualitative rather than quantitative methods. Such studies have historically been limited to identification of issues via interviews, surveys, and mixed methods designs, and are typically aimed at identifying the frequency and relative importance using rank analysis approaches (such as the relative importance index, frequency index, severity index, importance index, relative importance weight, mean score, rank correlation coefficient, weighted opinion average, and importance weight, etc.). This study sought to build upon previous literature by collecting project management documents to empirically capture issue management and project performance data of construction project teams. Such data provides an empirically grounded view of the challenges encountered by construction project teams.

A previous empirical study of issue management in construction was conducted by Shalwani and Lines (2020). Their study identified a rank-order of the most frequently occurring types of issues and when they typically occurred during the construction schedule of building projects. Their results showed that the most frequently occurring issues were designer and owner related, such as design errors and omissions, owner scope changes, and other owner internal issues. However, their study did not consider performance outcomes – such as cost and schedule growth – of those projects nor the extent to which the issues logs were used on a project-by-project basis among the project teams. The present study addresses these limitations through further analysis of the same data sample, shifting the focus from individual issue types to an intensity measure of issue log implementation within each project and investigating the corresponding effect on cost and schedule growth. In summary, the previous study identified the type of issues that tend to occur most frequently in construction (without considering project performance) whereas the present study analyzes how the extent of issue log usage among construction teams can improve project performance.

Research Objective and Hypotheses

The objective of this study was to investigate the extent and consistency of issue management implementation by construction project teams. The specific research questions were (1) what are the differences in performance outcomes of projects that implement issue management to a greater extent, and (2) do construction project teams tend to implement issue management in a consistent manner across the project schedule?

Research Question 6 (RQ6)

To address the first research question, the concept of issue management implementation (IMI) was developed as an overall measure of the project team's usage of an issue log to continually identify, monitor, and resolve individual issues that occurred during the construction phase. Measuring the project team's extent of issue management is important because the ultimate intent of using an issue log is to ensure a formal, standard, and professional system is being used to proactively identify and monitor issues in an effort to minimize their impact to project performance (wherever possible). However, some project teams may feel as though an issue log represents nothing more than extra paperwork to be completed. Considering this perception, it becomes important to provide empirical evidence of the project performance benefits that are gained from greater IMI. Such benefits – if found – may be motivating for project teams to treat their issue logs with greater formality and focus. Hypothesis 1 was formulated as follows to test the first research question:

Hypothesis Statement 8 (H8): Project teams that practice higher issue management implementation tend to achieve lower cost and schedule growth.

Research Question 6 (RQ6)

The second research question sought to reveal the consistency with which project teams utilized issue management across the project schedule. This is important for project teams to understand for a couple reasons. First, it can be reasonably expected that project teams may adhere to project control strategies, such as IMI, with varying levels of consistency across a single project. Therefore, it is important for project managers (and their supervisors) to be aware of whether there is a tendency for IMI to wane or "slack off" during certain points of a project. Second, it is also important to understand whether a project team's extent of IMI early in the project serves as an indicator of how the remainder of the project will be conducted. For example, if project teams start with high IMI (or conversely, low IMI), does this establish a trend that is likely to continue for the remainder of the project? If such a trend were revealed, project teams may be recommended to establish high IMI at the outset of their project in an effort to foster a more favorable trend for the project's duration. Hypothesis 2 was formulated as follows to test the second research question:

Hypothesis Statement 9 (H9): Project teams tend to use a consistent level of IMI throughout every quartile of the project schedule duration.

RESEARCH METHODOLOGY

Data Collection

The issue management and project performance data used in this study was collected from 19 public institutions to compile a total of 881 small building projects from United States and Canada. These institutions were selected on a voluntary basis and were screened to ensure their projects and facilities were of consistent scope before being deemed adequate for analysis. The researchers were actively involved with data collection during the construction phase of each project, wherein weekly issue logs were received from each project team. The researcher team received final project close out documentation from each of the project teams, which was submitted by the contractor's project manager for review and approval by both the owner's construction manager and procurement representative. The project close out documentation contained the awarded cost and schedule, final cost and schedule, a list of all change orders, and the final issue log. This close out documentation was compiled from completed projects to be analyzed in this study. To verify data accuracy, the researchers performed a comparison of the project close out documentation and the weekly submissions received throughout the construction phase. The close out documentation was used as the prevailing data source, since this documentation was used for each owner organization's audit records and was therefore considered as the official – and accurate – record of project information.

All projects in the dataset consisted of building construction projects delivered via the Design-Bid-Build (D-B-B) delivery method in the public institutional sector, including institutions of higher education, primary and secondary education, municipal governments, and the armed forces. Within these institutions, the projects in the data set were limited to education and healthcare facilities of similar size and scope. The educational projects in the data set were limited to construction work that occurred in classrooms, dormitories, dining centers, kitchens, offices, and basic teaching and research laboratories. The healthcare projects in the data set were limited to construction work that occurred in office spaces, common areas, dining centers, kitchens, convenience shops, and basic laboratory and general patient care facilities. The data set did not contain complex healthcare construction such as operating rooms or high-level research laboratories; therefore, the scope of construction work in both educational and healthcare projects was held to be reasonably similar. These projects were completed in the years 2003 to 2015 and were collectively referred to as "small building projects" since they were each limited to a maximum of $5M in total project value (the average awarded cost was less than $1M) and less than one year in project schedule (the average construction duration was 300 days). These project size characteristics are in line with previous studies that have investigated similar project types and categorized them as small building projects (Hurtado *et al.,* 2018; Hurtado *et al.,* 2017; Shehu *et al.,* 2014). Cumulatively, the total awarded cost for the entire data set was $824M and the cumulative final cost was $890M, representing a total cost increase of $66M. Lastly, all the project cost were normalized to year 2015, whereas, all the projects were analyzed in United States Dollars (USD). Table 1 provides additional characteristics of the data set.

Table 18. Data Characteristics

Demographics	Value
Owner Type	
University	236
Armed Forces	594
City/State/Federal	51
Facility Type	
Educational	287
Healthcare	594
Year of Completion	
2003 - 2010	739
2011 - 2015	142
Awarded Cost	
Mean awarded cost	$935,000
Median awarded cost	$597,000
Standard deviation of awarded cost	$976,000
Minimum awarded cost	$30,000
Maximum awarded cost	$4.80M
Cumulative awarded cost for data set	$824M
Final Cost	
Mean final cost	$1.01M
Median final cost	$637,000
Standard deviation of final cost	$1.03M
Minimum final cost	$32,900
Maximum final cost	$5.26M
Cumulative final cost for data set	$890M
Awarded Schedule	
Mean awarded schedule	300 days
Median awarded schedule	270 days
Standard deviation of awarded schedule	205 days
Minimum awarded schedule	31 days
Maximum awarded schedule	450 days
Final Schedule	
Mean final schedule	434 days
Median final schedule	366 days
Standard deviation of final schedule	315 days
Minimum final schedule	30 days
Maximum final schedule	550 days

Issue Logs used in Data Collection

The data used in the study was extracted from the finalized issue logs archived as a project document at the time of project closeout. In each project, an issue log was submitted by the contractor's project team on a weekly basis and then was finalized upon project completion. The issue log was maintained by the contractor's project team in guidance with PMBoK recommendations, where the project team was responsible to document each individual issue the project team encountered during construction, including information on the entity responsible for the issue, when the issues were identified and resolved, and the resulting impacts to project awarded cost and schedule (if any). An issue log was typically the first item a project team reviewed during its weekly meeting. During each meeting, the log was updated to reflect current progress on active issues, to indicate when issues were resolved and what their cost and schedule impacts were, and to document new issues. Furthermore, the issue log also contained the original awarded cost and schedule duration along with the approved final values of project cost and schedule duration. Cumulatively, a total of 5,635 individual issues were gathered for analysis, where on average 6 issues occurred per project, with a minimum of 1 issue identified and a maximum of 20 issues for a project. All projects in the data set utilized the same issue log structure. Data integrity was verified by using the final issue log upon project completion to ensure a complete view of construction activities was captured. The final issue log was checked against the owner's project close out documentation (typically inclusive the final issue log) which was held as part of the organization's auditable project records and was therefore considered to be highly accurate.

Definition of Variables

There were two groups of variables used in this study – project performance and issue management implementation – each of which are defined in the sub-sections below.

Project Performance

Cost and schedule growth are among the most widely used performance metrics in the construction industry (Shdid *et al.,* 2019; Shrestha and Maharjan, 2018), hence, in this study cost and schedule growth were used as project performance metrics.

Cost Growth: Cost growth was calculated on a per project basis. Cost growth was defined as the percent difference between the awarded and the final cost of a project, as calculated using the formula below:

$$Cost\ Growth = \left(\frac{Final\ Cost\ of\ the\ Project - Awarded\ Cost\ of\ the\ Project}{Awarded\ Cost\ of\ the\ Project}\right) \times\ 100\%$$

Schedule Growth: Schedule growth was calculated on a per project basis. Schedule growth was defined as the percent difference between the awarded and the final duration of a project, as calculated using the formula below:

$$Schedule\ Growth = \left(\frac{Final\ Schedule - Awarded\ Schedule\ of\ the\ Project}{Awarded\ Schedule\ of\ the\ Project}\right) \times\ 100\%$$

To keep analysis consistent, all projects with a deductive impact were removed from the analysis, which were relatively rare and represented less than 10 projects in the dataset that had a deductive impact.

Issue Management Implementation

Issue Management Implementation (IMI) attempts to distinguish the extent to which individual project teams utilized issue management practices in the construction phase. IMI was categorized into three levels of High, Moderate, and Low implementation of issue management practices. Mathematically, IMI is expressed as a ratio of the Non-Impactful Issues (issues that were tracked on the issue log but did not ultimately affect the project's awarded cost or schedule) to the overall total number of issues documented by the project team throughout the project. IMI was calculated using the following formula:

$$IMI = \left(\frac{Total\ Number\ of\ Non\text{-}Impactful\ Issues\ tracked\ in\ the\ project\ Issue\ Log}{Total\ Number\ of\ Issues\ tracked\ in\ the\ project\ Issue\ Log}\right) \times\ 100$$

Low Issue Management Implementation (Low IMI): corresponds with project teams who practiced little to no usage of the issue log for issue management purposes. Projects in the Low

IMI category had fewer than 33% of identified issues as Non-Impactful Issues. Low IMI can be numerically expressed as 0% < IMI ≤ 33%. In these cases, the project team's issue log was essentially reduced to tracking the change orders that occurred during the project since little else was documented (e.g. little to no instances of formally tracking *potential* issues that ultimately became Non-Impactful Issues).

Moderate Issue Management Implementation (Moderate IMI): corresponds with project teams that showcased a moderate usage of issue management. Projects in the Moderate IMI category had between 33% and 67% of identified issue as Non-Impactful Issues. Moderate IMI can be numerically expressed as 33% < IMI ≤ 67%.

High Issue Management Implementation (High IMI): corresponds with project teams that identified, tracked, and monitored issues on a very thorough basis. Projects in the High IMI category had more than 67% of their total issues as Non-Impactful Issues, which roughly corresponds to a greater usage of issue management to track a greater portion of issues with the potential to impact cost or schedule. High IMI can be numerically expressed as IMI ≥ 67%.

METHOD OF ANALYSIS

The dataset was analyzed to determine how effectively and consistently project teams utilized issue management practices to control project cost and schedule. Differences between groups were determined using the Kruskal-Wallis H test with post-hoc testing via the Mann-Whitney U test with pairwise comparison. The Kruskal-Wallis H test was employed instead of one-way ANOVA because the data were not normally distributed (Kolmogorov–Smirnov test resulted in p-value < 0.05 for all test conducted, thereby failing the test for normality) and had outliers, thereby violating the two primary assumptions of one-way ANOVA. In contrast, all the assumptions of the Kruskal-Wallis H test were satisfied and is not affected by the outliers in the sample size. The data had independence of observation, meaning there was no relationship between the observations in each independent variable group or between the groups. Further, visual inspection of a box plot indicated that all categorical variables were similar in shape.

RESULTS

Objective 1: Relationship between Issue Management Implementation and Project Performance

Table 2 provides the descriptive statistics of cost and schedule growth for the three levels of IMI; High, Moderate, and Low. On average, project teams that utilized High IMI had a cost and schedule growth of 6.3% and 35.3% respectively. Moderate and Low IMI projects had cost growth of 9.4% and 10.6%, respectively, and schedule growth of 47.6% and 40.6%, respectively. Further analysis was conducted using the Mann-Whitney U test to determine which of the three levels of IMI were statistically different for cost and schedule growth.

Table 19. Descriptive of Issue Management Implementation for Cost and Schedule Growth

	Projects with Cost Growth						Projects with Schedule Growth					
IMI	N	Mean	Median	Std. Dev.	Min.	Max.	N	Mean	Median	Std. Dev.	Min.	Max.
High	119	6.3%	3.9%	9.7%	-31.6%	41.3%	139	35.3%	21.7%	36.8%	-24.3%	149.5%
Moderate	210	9.4%	5.5%	10.5%	-15.5%	49.3%	175	47.6%	35.0%	40.6%	-40.7%	145.9%
Low	235	10.6%	7.3%	9.5%	-4.4%	44.5%	279	40.6%	33.6%	42.3%	-55.1%	147.5%

Results showed that High IMI projects had a statistically significantly lower cost and schedule growth compared to project teams that utilized Moderate and Low IMI. Table 3 shows the results from the inferential analysis between the three levels of IMI to cost and schedule growth. With regards to projects that experienced cost growth, all three levels of IMI were found to be significantly different from each other (p = 0.05), where High IMI projects tended to have lowest cost growth and Low IMI projects tended to have the highest cost growth. On an average, High IMI projects had 3.1% to 4.3% lower overall cost growth compared to Moderate and Low IMI projects.

With respect to schedule growth, High IMI projects were found to have statistically lower schedule growth than Moderate or Low IMI projects ($p = 0.05$). On average, High IMI projects were 5.3% to 12.3% better in terms of overall schedule growth performance compared to Moderate or Low IMI projects.

Table 20. Post hoc test between Issue Management Implementation for Cost and Schedule Growth

Projects with Cost Growth						Projects with Schedule Growth					
Base Category	Median	Comparison Category	Median	Test-statistics	*p*-value	Base Category	Median	Comparison Category	Median	Test-statistics	*p*-value
High	3.9%	Moderate	5.5%	-2.340	0.004*	High	21.7%	Low	35.0%	-2.182	0.050*
High	3.9%	Low	7.3%	-4.153	0.000*	High	21.7%	Moderate	33.6%	-2.987	0.004*
Moderate	5.5%	Low	7.3%	-2.075	0.037*	Low	35.0%	Moderate	33.6%	-1.165	0.199

*p < 0.05

Further analysis was conducted where the number of Impactful Issues per project were kept constant for each level of IMI. This was done to ensure the number of Impactful Issues in each level of IMI were not impacting the overall cost and schedule growth. For example, as shown in Table 4, the row labeled as “1 Impactful Issue” corresponds to all projects which had a single issue that resulted in either a cost or schedule impact. These projects were then split into the three levels of IMI (High, Moderate, and Low) more clearly delineate which projects tracked a greater number of Non-Impactful Issues. A similar approach was used for the following two rows, which show projects that had 2 Impactful Issues and 3 or more Impactful Issues, respectively. The intent of this analysis was to control for the number of Impactful Issues that were experienced by the projects to more clearly isolate the IMI levels practiced by the project team.

Table 21. Kruskal-Wallis H test between Issue Management Implementation and Cost and Schedule Growth for Controlled Impactful Issues

# of Impactful Issues	IMI	Cost Growth				Schedule Growth			
		N	Mean	Test Statistics	p-value	N	Mean	Test Statistics	p-value
1 Impactful Issue	High	73	5.6%	6.444	0.040*	83	28.5%	9.847	0.007*
	Moderate	86	8.1%			77	35.1%		
	Low	62	7.2%			124	20.4%		
2 Impactful Issues	High	22	6.2%	1.455	0.483	29	31.7%	13.273	0.001**
	Moderate	47	10.9%			28	63.7%		
	Low	50	10.9%			77	51.5%		
≥ 3 Impactful Issues	High	24	8.5%	4.681	0.096**	27	59.8%	5.451	0.046*
	Moderate	77	10.0%			67	53.9%		
	Low	123	12.1%			79	65.5%		

*p < 0.05
**p < 0.1

Table 4 shows the results from inferential analysis with the number of Impactful Issues kept constant for the three levels of IMI and their corresponding cost and schedule growth. The following findings were reported:

- When controlling for projects that had 1 Impactful Issue (221 total projects), different levels of IMI were found to have statically significant result for both cost and schedule growth (p = 0.05). It was found that High IMI projects had statistically significant *lower* cost and schedule growth when compared Low and Moderate IMI projects.
- When controlling for projects that had 2 Impactful Issues (119 total projects), there was no statistically significant difference in cost and schedule growth for different levels of IMI at p-value of 0.05. However, schedule growth was found to be statically significant at the 90 percent confidence interval (p = 0.1), where High IMI projects had *lower* schedule growth compared to Low and Moderate IMI projects.
- When controlling for projects that had 3 or more Impactful Issues (224 total projects), different levels of IMI were found to have a statically significant result for cost growth at the 90 percent confidence interval and schedule growth at the 95 percent confidence interval. High IMI projects were found to have *lower* cost growth to the Moderate and Low

IMI projects. Similarly, High IMI projects was *lower* schedule growth than Low IMI projects but *higher* schedule growth than Moderate IMI projects.

Overall, High IMI projects tended to achieve better cost and schedule performance compared to Moderate or Low IMI projects, which bolstered the results from the initial inferential testing amongst the three IMI levels and project performance. Among the statistically significant results, High IMI projects showed the potential to reduce cost growth by as much as 1.5% to 3.6% and schedule growth by 5.7% to 32.0%. Therefore, the reduction in cost and schedule growth among High IMI projects shows that issue logs can be used as an effective tool to improve construction project performance.

Objective 2: Consistency of Issue Management Implementation across the Construction Schedule

Figure 1 shows the three levels of IMI (High, Moderate, Low) across the schedule quartiles for projects that have experienced some amount of cost growth. Further analysis was conducted to determine if the three levels of IMI were significantly statistically different from each other for every project schedule quartile.

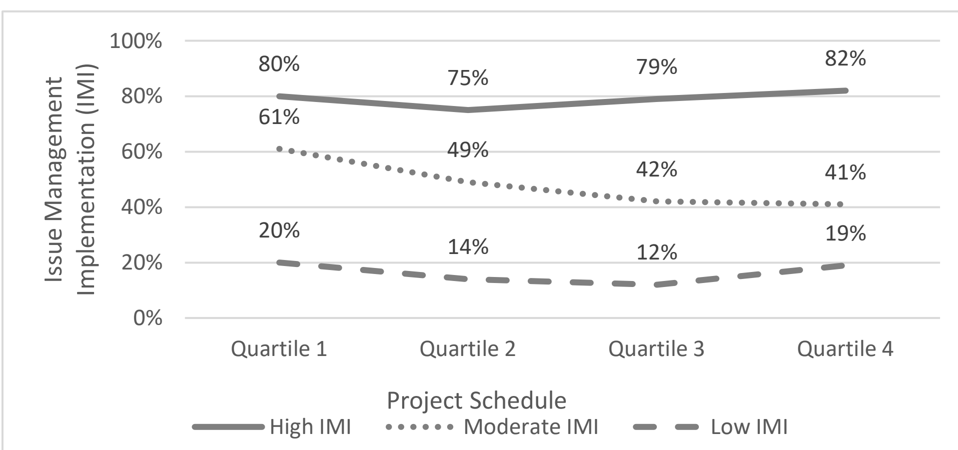

Figure 1. Issue Management Implementation by Schedule Quartile for Projects with Cost Growth

For projects that experienced any amount of cost growth, High IMI projects tended to maintain high IMI values throughout the project schedule. Table 5 shows results from the inferential analysis conducted for every project schedule quartile between the three levels of IMI. For each of the project schedule quartiles, all three IMI levels were found to be statistically different (p = 0.05), where High IMI projects had the highest IMI values compared to Moderate and Low IMI projects. On average, across each schedule quartile, High IMI projects had IMI values between 75% to 82%, compared to Moderate IMI projects with 41% to 61%, and Low IMI projects with 12% to 20%.

Table 22. Kruskal Wallis H test for Levels of IMI across Quartiles of the Project Schedule (for Projects that Experience Any Amount of Cost Growth)

Schedule Quartile	Issue Management Implementation	N	Mean	Median	Std. Deviation	Minimum	Maximum	*p*-value	Post-Hoc
1st	High	107	80%	100%	32%	0%	100%	0.000*	All levels were different
	Moderate	126	61%	67%	40%	0%	100%		
	Low	113	20%	0%	26%	0%	100%		
2nd	High	99	75%	92%	33%	0%	100%	0.000*	All levels were different
	Moderate	146	49%	50%	41%	0%	100%		
	Low	151	14%	0%	26%	0%	100%		
3rd	High	103	79%	100%	31%	0%	100%	0.000*	All levels were different
	Moderate	141	42%	50%	41%	0%	100%		
	Low	138	12%	0%	25%	0%	100%		
4th	High	86	82%	100%	36%	0%	100%	0.000*	All levels were different
	Moderate	120	41%	100%	43%	0%	100%		
	Low	107	19%	0%	33%	0%	100%		

*p<0.05

Similarly, Figure 2 shows the three levels of IMI (High, Moderate, Low) across the schedule quartiles for projects that have experienced some amount of schedule growth. Further analysis was conducted to determine if the three levels of IMI were statistically different from each other for each project schedule quartile.

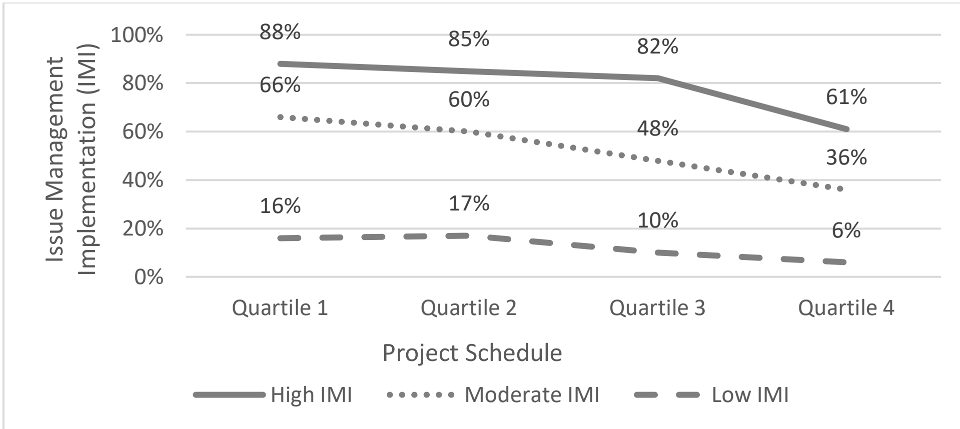

Figure 2. Issue Management Implementation by Schedule Quartile for Projects with Schedule Growth

For projects that experienced any amount of schedule growth, High IMI projects tended to maintain high IMI values throughout the project schedule. Table 6 shows the result from the inferential analysis conducted for every project schedule quartile between the three levels of IMI. For each of the project schedule quartile, all three IMI levels were found to be statistically different (p = 0.05), where High IMI projects had the highest IMI values compared to Moderate and Low IMI projects. On average, across each schedule quartile, High IMI projects had IMI values between 61% to 88%, compared to Moderate IMI projects with 36% to 66%, and Low IMI projects with 6% to 16%.

Table 23. Kruskal Wallis H test for Levels of IMI across Quartiles of the Project Schedule (for Projects that Experience Any Amount of Schedule Growth)

Schedule Quartile	Issue Management Implementation	N	Mean	Median	Std. Deviation	Minimum	Maximum	*p*-value	Post-Hoc
1st	High	127	88%	100%	25%	0%	100%	0.000*	All levels were different
	Moderate	130	66%	67%	37%	0%	100%		
	Low	110	16%	0%	33%	0%	100%		
2nd	High	127	85%	100%	27%	0%	100%	0.000*	All levels were different
	Moderate	148	60%	67%	40%	0%	100%		
	Low	141	17%	0%	33%	0%	100%		
3rd	High	127	82%	100%	30%	0%	100%	0.000*	All levels were different
	Moderate	144	48%	50%	41%	0%	100%		
	Low	143	10%	0%	25%	0%	100%		
4th	High	111	61%	75%	40%	0%	100%	0.000*	All levels were different
	Moderate	122	36%	17%	41%	0%	100%		
	Low	175	6%	0%	19%	0%	100%		

*p<0.05

DISCUSSION

Objective 1: Relationship between Issue Management Implementation and Project Performance

Results showed that projects which utilized different levels of IMI achieved different cost and schedule growth outcomes; therefore, H8 was accepted. In general, project teams that practiced High IMI tended to attain more favorable cost and schedule growth performance, which indicates that issue logs can be used to improve construction project performance. More specifically, projects that utilized High IMI on average achieved a 3.1% to 4.3% reduction in cost growth and 5.3% to 12.3% reduction in schedule growth when compared with Moderate and Low IMI projects, respectively (as shown in Tables 3 and 4). This result indicates that more extensive issue management practices tend to translate into more favorable project outcomes. These results were found to be consistent with previous studies that have found that other project control tools, such as Earned Value Analysis (Hanna 2012) and Control Charts (Salehipour *et al.,* 2016), result in better project performance outcomes when used to a greater extent.

One possible explanation can be observed in a study by Huang *et al.* (2020), which analyzed 221 construction projects and found that transparent communication and knowledge sharing among project team members was directly associated with reductions in project cost and schedule growth. The issue log tool used in this study was specifically structured as a formal mechanism to communicate issues and transparently track their potential impacts to cost and schedule. This type of transparent information sharing may have better positioned the project stakeholders to take proactive responses to mitigate the impacts of the issues that were communicated on the issue log.

The mere fact that there were such differing levels of issue management implementation among the projects in the dataset is notable. Such disparity may be a manifestation of the "adversarial" relationships that are commonly attributed to the construction industry (Yui *et al.,* 2011). For example, Pesek *et al.* (2019) found that prime contractors tended to delay communication of design document deficiencies to their owners; in fact, almost half (46%) of contractors stated that delaying the notification of document deficiencies found in the bidding period was most financially profitable when delayed well into the construction phase. The study concluded by noting that a possible reason for this is that contractors' and owners' interests are sometimes in opposition. In turn, transparent communication of issues can be hindered. Other studies have found similar results in other areas of the construction project team relationship; for example, Javanmardi *et al.* (2018) found that subcontractors have been known to withhold information about site issues from the prime contractor until the cost and/or schedule impact of those issues were already prepared for change order purposes. This type of behavior would certainly limit the issue management ability of the construction team because general contractors often must rely upon their subcontractors to communicate issues that are encountered in the source of the subcontractors' work.

Another element that can limit issue management is the fact that project stakeholders each have different risk tolerances, such that one stakeholder may choose to withhold the knowledge of a potential issue because they personally feel that the risk of cost or schedule impact is not great enough to warrant its communication. Yet based on the results of this study, project teams are recommended to actively foster a project environment wherein all stakeholders are encouraged to communicate knowledge of potential issues as early as possible.

Objective 2: Consistency of Issue Management Implementation across the Construction Schedule

Results showed that the extent to which IMI was practiced by project teams tended to remain consistent throughout the project schedule; therefore, H9 was accepted. Project teams with High IMI in the first quartile of the project schedule duration tended to maintain this practice for the rest of the schedule duration. Projects with Moderate and Low IMI in the first schedule quartile also continued their respective trends for the remainder of the project (as shown in Tables 5 and 6). These results were found to be consistent with the results from Mossalam (2018) which found that one major reason why project teams practice different levels of IMI on the project is due to a lack of training.

The establishment of thorough issue management practices early in the schedule may therefore have crucial implications for the rest of the project. This establishment of an early "norm" of project team behavior would be consistent with popular research in the field of organizational behavior, such as the famous "forming-storming-norming-performing-adjourning" model of group development first proposed by Tuckman and Jensen (1977). Previous studies of construction teams' behavior have concluded that healthy project team development – including an atmosphere that engenders higher levels of commitment, trust, openness, transparent communication, and knowledge sharing – should be established early in the project because the project team tends to maintain the acquired behavior throughout the rest of the project (Jiang *et al.,* 2016; Brewer and Strayhorn, 2012).

The fact that IMI levels were consistent across the construction schedule also indicates that issue management is an active, ongoing effort that requires attention throughout the entire construction process. Identifying issues is an iterative and a continuous process that must be carried out on a regular basis throughout the project lifecycle (Siraj *et al.,* 2019). Previous studies have also shown that issues may be encountered at any point in the project schedule, thereby necessitating continual focus and input from the project team. (Shalwani and Lines, 2020). Project teams are therefore recommended to foster a proactive attitude of continuous issue identification and formal communication by means of the project's issue log.

CONCLUSIONS AND CONTRIBUTIONS

Project control strategies such as issue management are important in the construction industry where cost and schedule overruns are widespread. The PMBoK and past research has recommended the use of issue logs as an opportunity for project teams to effectively communicate, track, and respond to the various issues that may occur during the project. Gaps in the issue management literature include a lack of studies that quantitatively and empirically document issue management rather than using qualitative designs, an over-reliance on input from individual stakeholders rather than the consensus of the entire project team, and a lack of results regarding how the specific tool of issue logs are used in construction projects. This study addressed those gaps by analyzing 881 project issue logs, which consisted of quantitative and empirical data, represented the consensus of the major project stakeholders, and documented information related to the timing, cost impacts, and schedule consequences of individual issues, all of which illuminate the extent to which construction teams utilized issue logs.

The results showed that projects tended to achieve lower rates of cost and schedule growth when project teams utilized issue logs to a greater extent. This study also found that project teams tended to maintain their level of issue management implementation, whatever the extent may be, from the beginning of the project schedule until the end. This finding suggests that that project teams may tend to formulate and then normalize their issue management practices early in the project schedule.

Contributions to the Body of Knowledge

This study adds to body of knowledge by analyzing a relatively large sample size of 881 small building construction projects from 19 various institutions from across United States and Canada with a total of 5,365 individual issues that occurred during the construction phase of those projects. Analyzing these individual issues is a unit of measure that is seldom used in the previous construction literature, which more commonly utilizes change orders rather than the underlying individual issues. In response to previous studies (e.g. Dikmen *et al*. 2018) which recommended the use of more empirical methods to quantity project team consensus in the areas of risk and issue management, the dataset in this study was comprised entirely of issue logs which represented empirical project documentation and reflected the consensus of all project stakeholders.

Contributions to Industry Practitioners

The results also contribute to practitioners by providing evidence that more extensive use of issue logs tends to correspond with higher performing projects in the areas of cost and schedule growth. This finding may be motivating for project teams to place strong emphasis on issue logs as a valuable project control tool. Several recommendations can be inferred from the results, including:

- Project teams should consistently utilize issue logs in accordance with recommended issue management practices, such as early identification, monitoring, and resolution of issues, because these practices result in better project performance outcomes.

- Project teams should make a practice of using issue logs early on in the project, because project teams tend to maintain this early established level of utilization for the remainder of the project duration.
- Project teams should be open, transparent, and fair in their communication of issues. This will help to foster an environment of trust, where project teams can identify issues much early and make necessary measures to resolve the issue, thereby either minimizing or eliminating a potential negative impact on project performance.
- Although the results of his study are only directly applicable to small building construction projects in the United States and Canada, similar recommendations can be extended to other projects in other regions, where effective use of issue logs from the start of the project (followed by open and transparent communication among project stakeholders) may manifest similar results.

LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

There are a several limitations to this study. First, the results were limited to small building projects that were constructed in the United States and Canada and delivered using the D-B-B delivery method. Second, the study was limited to analysis of issues that occurred during the construction phase of the project and did not consider pre- or post-construction phases. Future research could conduct similar analysis in the context of different project types or delivery methods such as Design-Build (D-B) and Construction Manager at Risk (CMAR). Furthermore, a similar analysis could be conducted to determine how the identification and resolution timings of different issue types contribute to the overall project performance.

CHAPTER 5: CONCLUSION

SUMMARY

The objective of the dissertation was to investigate the characteristics of issue management in small building construction projects and the extent to which issue management provides an effective project control tool in that setting. To investigate this topic, the dissertation was divided in to three research objectives as follows:

- To investigate the extent to which different Issue Types (which are the underlying causes of change orders) contribute to the overall project cost and schedule growth.
- To investigate the frequency with which different Issue Types arise during the construction phase and to identify the timing of the project team's corresponding Issue Management actions (Issue Identification, Issue Resolution, and Issue Monitoring Period) to minimize the impact of each issue.
- To investigate how different levels of Issue Management Implementation undertaken by project teams may be related to more favorable project performance outcomes.

Data was gathered from the finalized issue log submitted by the contractor (and approved by the owner) during the time of project closeout. The sample size consisted of 881 small building construction projects from 19 public institutions across the United States and Canada and delivered via Design-Bid-Build (D-B-B) delivery method. Within these institutions, the projects in the data set were limited to education and healthcare projects of similar size and scope. These projects were completed in the years 2003 to 2015 and were each limited to a maximum of $5M in total project value (the average awarded cost was less than $1M) and less than one year in project schedule (the average construction duration was 300 days)

DISCUSSION OF DISSERTATION-WIDE FINDINGS

Construction projects encounter a variety of issues that can impact project performance, yet this study provides empirical evidence that unwanted cost and schedule deviations can be avoided with proper project planning and appropriate use of project control tools and techniques. The following sections provide discussion of dissertation-wide findings to provide holistic guidance to practitioners across all three papers.

Key Findings

The findings of this dissertation can be summarized at two different levels:

- First, at the level of an individual project.
- Second, at the level of entire programs of projects managed by a public institution.

Coalescing the key findings of the dissertation across these two levels can help industry practitioners monitor and control their projects in a more effective manner.

Project Level

Figures 3 and 4 each provide a graphical representation of findings from across the dissertation. The figures show bubble charts of the various issue types, their frequency of occurrence on a per-project basis, and the average issue identification timing during the planned project schedule. The magnitude of impact (measured in terms of cost and schedule growth) was represented by the size of each bubble. Combining the results of this dissertation, the following inferences can be made at the project level:

- As shown in the figures, owner- and designer-related issues were the most frequently occurring issues in small building projects. These were generally identified and resolved at a moderate point in the project schedule relative to the other issue types; however, they contributed the most to the cost and schedule growth of a project. Therefore, these issue sources are recommended to receive increased attention.

- Contractor-related issues occurred at a moderate rate during construction. These issues were identified and resolved the latest during the project schedule, but only moderately impacted the cost and schedule growth.
- Unforeseen issues, such as concealed, weather, and other conditions were found to be the least frequently occurring issues during projects. These issues were identified and resolved the earliest and contributed moderately to the overall cost and schedule growth of a project.

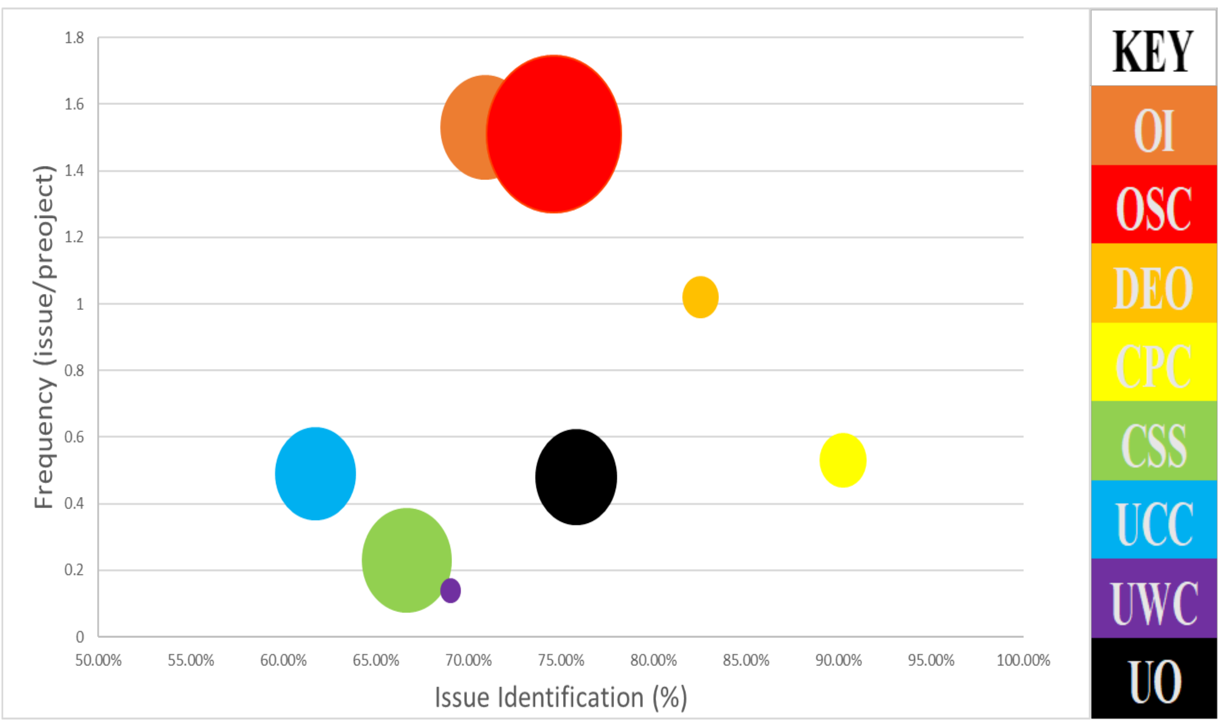

Figure 3. Bubble Chart of Cost Impact by Issue Types and Average Issue Identification

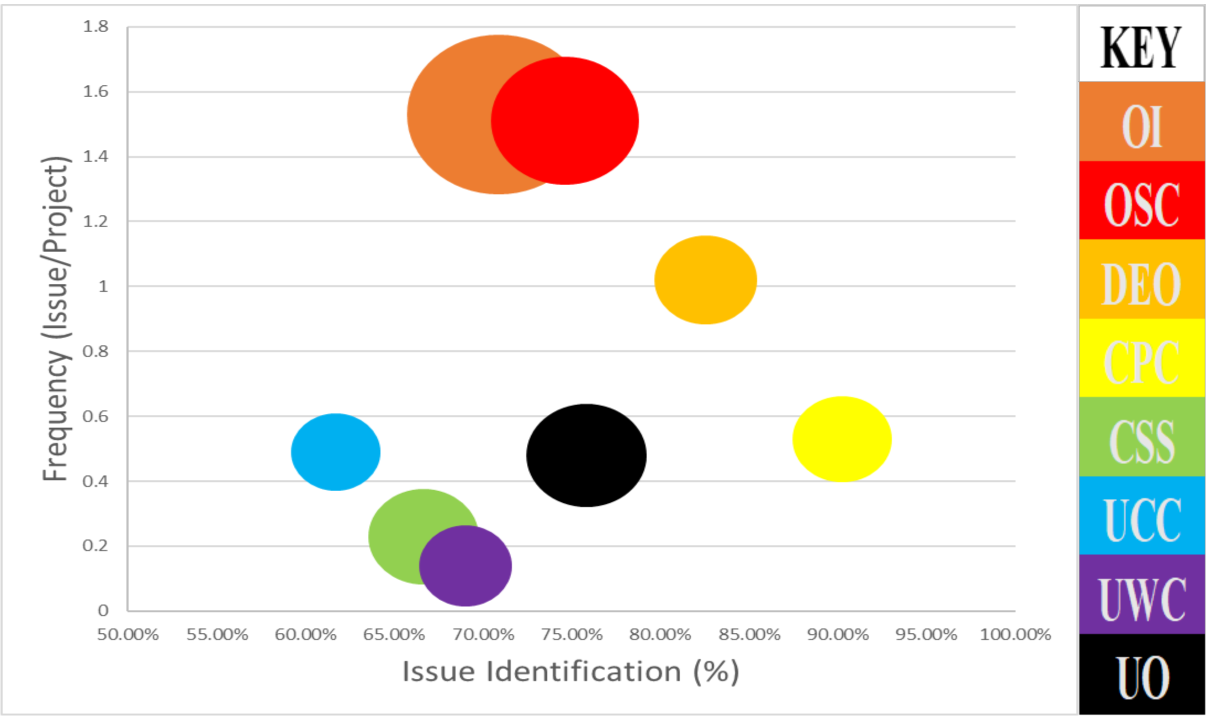

Figure 4. Bubble Chart of Schedule Impact by Issue Types and Average Issue Identification

Project teams should focus on issues which have the greatest impact to project performance. Project teams should also consider the frequency of issues because the most frequently occurring issues corresponded with the issue types that had the greatest impact on cost and schedule growth. These include owner internal and owner scope changes, designer errors and omissions, and unforeseen concealed conditions. Therefore, during the planning stages of the project, project teams can work to identify the most probable risks associated with these issues and develop contingency plans to ensure the project does not result in cost and schedule growth. Furthermore, proactive plans can be developed to eliminate these issues from ever arising on the project, which may include but are not limited to changes to project budget, schedule, management plan, and project team expertise.

Beyond the planning phase, the inferences from this study's results can also be applied during the execution (construction) phase to help project teams reduce the chances of negative project performance outcomes. A rigorous upfront planning phase can become expensive in both time and resources, which is something that institutions must be sensitive to given the that these results apply to the context of small building projects which individually represent small expenditures and shorter timelines. In the context of small building process, project teams should be proactive in identifying most critical issues early on and, once identified, should closely monitor and resolve them as soon as possible. Such practices have shown to impact the cost and schedule of the project at lower magnitude as opposed to when these issues were identified and resolved later in the project. In addition to early identification and resolution, project teams should also practice high utilization of issue management throughout the project which includes proactively identifying, monitoring, and managing issues from the start through the end of the project, which have shown to reduce the cost and schedule growth.

Program Level

Inferences can also be made from the results of this study at program level, including:

- Small projects (< $375k) tended to have the greatest cost growth, whereas large projects ($1M to $5M) tended to have the greatest schedule growth. This result shows that institutions may not be able to prioritize projects solely based on size, since projects of all sizes were exposed to substantial risk of either cost or schedule growth.
- The various Issue Types impacted the cost and schedule growth similarly across all project sizes. This result underscores the effectiveness of taking a program- or portfolio-wide perspective, since any progress made in reducing the impact of a particular issue type will be efficacious across the institution's entire portfolio.
- Issue Management Implementation appears to be a contributing factor to overall project performance, such that project teams who practiced High Issue Management

Implementation (defined as being more transparent in identifying and formally tracking potential issues) tended to achieve better project performance outcomes.

- Project teams appeared to utilize a relatively consistent level of Issue Management Implementation across the project schedule. For example, project teams who started the first quartile of the project schedule with High (or Low) Issue Management Implementation tended to continue this through the remaining schedule quartiles. Data analysis shows that the project teams who practiced High Issue Management Implementation throughout the project schedule tended to achieve more favorable project performance outcomes.

Effective upfront planning and implementing best practices in issue management during the construction phase can be a part of strategic plan across an institution's entire portfolio of construction projects, irrespective of project size. Majority of public institutions undertake numerous projects of similar scope every year (Hurtado et al., 2017); therefore, incorporating best practices in issue management across all the projects will not only save individual projects from excessive cost and schedule growth but can also help institutions control the cost and schedule growth of the entire portfolio (Mossalam 2018).

Implementing consistent and effective issue management practices can also help institution develop a robust tracking system which can become part of the organizational process assets and be used as a baseline for future projects (Rodríguez-Labajos et al., 2018). This can further strengthen institutions' knowledge base by creating a repertoire of issue types that are historically documented to affect projects the most. Historic information can also track the timing of occurrence of these issues, corresponding management practices that are proven to be effective, and accurate prediction of cost and schedule impact on an issue-by-issue basis. Such information can also be analyzed according to contractor type and project information including scope, size, location, and other project demographics. Considering that these institutions undertake numerous small building projects each year, tailored issue management practices for different type of projects (as well as specific building locations) can be implemented based on historical data to ensure more predictable performance outcomes across the entire portfolio.

Lastly, implementing such strategies at the program level will require an organization-wide change management initiative. Project teams should be trained and incentivized on effective tracking of issue from the very beginning of the project through its completion. Furthermore, project managers should also be trained to emphasize the necessity of actively identifying and resolving issues amongst their project team, even in cases where those issues never ultimately result in a cost or schedule impact. When implemented in an organization-wide manner, such practices can help institutions create an issue tracking system which will enhance the institution's knowledge base and ultimately benefit all future projects in the portfolio.

RESEARCH CONTRIBUTION

Contribution to the Body of Knowledge

This study adds to the body of knowledge by analyzing a relatively large sample size of 881 small building construction projects, procured via D-B-B delivery method and in the vertical sector. Furthermore, this study analyzes 5,635 individual issues that occurred during the construction phase of the projects. This study empirically identifies and quantifies the issues that occur with the most frequency and greatest impact to cost and schedule growth, which was previously limited to qualitative identification and magnitude of the impact. Lastly, this study provides an insight at a granular level, where each issue was analyzed, including the issue management practices undertaken by the project team to manage and monitor individual issues during the construction phase.

Contribution to the Construction Industry

One of the overarching objectives was to relate the findings back to the industry professional by drawing from past project performance analysis and educating the project teams on issues that have high chances of causing cost and schedule growth. Industry practitioners can create a strategic plan for small building construction programs, focusing on issues that are most common and cause the most deviation to the cost and schedule. Furthermore, project teams can develop effective issue management plan for issues that are most common or are being identified and resolved very late on the project, which also include using issue log as effectively as possible to track and monitor issues throughout the projects for better project performances.

LIMITATIONS

There are several limitations to this study, including:

- This study depicts the results for small building construction projects from the United States and Canada and may not be representative of other project types or locations.
- This study utilized data from 5,635 individual issues spread across 881 projects. Although project teams were trained on how to assign an issue type to each issue, there is still the chance of some subjectivity. However, the data was gathered from the finalized issue log from each project. Since this final issue log was submitted by the contractor and approved by the owner, it was assumed to be an acceptable consensus of the project team's view. Therefore, the data was assumed to be open to limited subjectivity because

the contractor and owner both agreed to each issue type, timing, and impact that was assigned to individual issues.

- The results of this study are also limited to project scopes that were relatively simple and straightforward rather than highly complex. The scopes tended to be projects in the context of healthcare and educational projects, which included common rooms, dormitories, office spaces, kitchens, and residence areas.

FUTURE RESEARCH

Future research is recommended to address the above limitations and build upon current results. Several recommendations for future research are listed below:

- Model simulation such as Monte Carlo and multivariate analysis can be conducted to determine the relative weights, identification, resolution, and monitoring period that can result in the minimum amount of cost and schedule growth during construction.
- Similar analysis could also be conducted and expanded to different project characteristics such as procurement type (Best Value (BV), Qualifications-Based Selection (QBS), or sole source), owner type (public, private, or other sub-categories), project types (horizontal or vertical), and contractor type (electrical, mechanical, civil, or prime contractor).
- Another potential future topic is to take the same study and expand it by adding another Issue Management parameter of Issue Prolongation. Not every issue resolved was resolved at the planned resolution date, hence, Issue Prolongation is the time from which an issue was prolonged from its planned resolution date. Such analysis can provide the

project team with issues that are prolonged the most, their impact (if any) on cost and schedule growth and causes of prolongation.

- Potential future study also includes analysis of the peak of issue level (number of issues being managed by the project team) on the project and the corresponding relationship with project cost and schedule growth
- Further analysis of why greater extent of Issue Management Implementation (IMI) practice leads to better project performance outcomes is also recommended.

REFERENCES

Aibinu, A. A., and Odeyinka, H. A. (2006). “Construction delays and their causative factors in Nigeria.” *Journal of Construction Engineering and Management*, *132*(7), 667-677.

Alaghbari, W.E., Kadir, M.R.A., and Salim, A. (2007). “The significant factors causing delay of building construction projects in Malaysia.” *Engineering Construction and Architectural Management, 14*(2), 192-206.

Alinaitwe, H., Apolot, R., and Tindiwensi, D. (2013). “Investigation into the causes of delays and cost overruns in Uganda's public sector construction projects.” *Journal of Construction in Developing Countries, 18*(2), 33-47.

Allen, L, N. (2001). “Comparison of design-build to design-bid-build as a project delivery method (Master’s thesis).” Naval Postgraduate School, Monterey, CA.

Al-Khalil, M. I., and Al-Ghafly, M. A. (1999). “Important causes of delays in public utility projects in Saudi Arabia.” *Construction Management and Economics, 17*(5), 641–655.

Al-Momani, A. H. (2000). “Construction delay: a quantitative analysis.” *International Journal of Project Management, 18*(1), 51-59.

Alp, N., and Stack, B. (2012, July). “Scope management and change control process study for project-based companies in the construction and engineering industries.” *Proceedings of PICMET'12: Technology Management for Emerging Technologies* (pp. 2427-2436). Vancouver, BC, Canada: IEEE.

Anastasopoulos, P. C., Labi, S., Bhargava, A., Bordat, C., and Mannering, F. L. (2010). “Frequency of change orders in highway construction using alternate count-data modeling methods.” *Journal of Construction Engineering and Management, 136*(8), 886-893.

Antoine, A. L., Alleman, D., and Molenaar, K. R., (2019). "Examination of project duration, project intensity, and timing of cost certainty in highway project delivery methods." *Journal of Management in Engineering, 35*(1), 04018049.

Apipattanavis, S., Sabol, K., Molenaar, K.R., Rajagopalan, B., Xi, Y., Blackard, B., and Patil, S. (2010). "Integrated framework for quantifying and predicting weather-related highway construction delays." *Journal of Construction Engineering and Management*, *136*(11), 1160-1168.

(ASCE) American Society of Civil Engineers (2017). "2017 Infrastructure Report Card." Retrieved from https://www.infrastructurereportcard.org/wp-content/uploads/2017/01/Schools-Final.pdf.

Asiedu, R. O., Frempong, N. K., and Alfen, H. W. (2017). "Predicting likelihood of cost overrun in educational projects." *Engineering, Construction and Architectural Management, 24*(1), 21-39.

Assaf, S. A., and Al-Hejji, S. (2006). "Causes of delay in large construction projects." *International Journal of Project Management, 24*(4), 349-357.

Badger, W. W., and Garvin, M. J. (2007, July). "Facilities asset management: challenges and opportunities." *Proceedings of the 25th Construction Management and Economics Conference* (pp. 301–313). University of Reading; United Kingdom: CME.

Braimah, N. (2014). "Understanding construction delay analysis and the role of preconstruction programming." *Journal of Management in Engineering, 30*(5), 04014023.

Brewer, G., and Strahorn, S. (2012). "Trust and the project management body of knowledge." *Engineering Construction and Architectural Management*, *9*(3), 286-305.

Call, S., Sullivan, K., and Smithwick, J. (2018). "The US healthcare facilities management industry's state of hiring from facilities management academic programs." *Journal of Facility Management Education and Research*, *2*(1), 19-25.

Cantarelli, C.C., Flyvbjerg, B, and Buhl, S.L. (2012). "Geographical variation in project cost performance: the Netherlands versus worldwide." *Journal of Transport Geography*, *24*(2012), 324-331.

Carpenter, N., and Bausman, D, C. (2016). "Project delivery method performance for public school construction: Design-bid-build versus CM at risk." *Journal of Construction Engineering and Management, 142*(10), 05016009.

Chen, Q., Xia, B., Jin, Z., Wu, P., and Hu, Y. (2015). "Choosing appropriate contract methods for design-build projects." *Journal of Management in Engineering, 32*(1), 04015029.

Col Debella, D., and Ries, R. (2006). "Construction delivery systems: A comparative analysis of their performance within school districts." *Journal of Construction Engineering and Management, 132*(11), 1131-1138.

Dikmen, I., Budayan, C., Talat Birgonul, M., and Hayat. E. (2018). "Effects of risk attitude and controllability assumption on risk ratings: Observational study on international construction project risk assessment." *Journal of Management in Engineering, 34*(3), 04018037.

Ellis, R.D., and Thomas, H.R. (2003). "The root causes of delays in highway construction", *Proceedings of the 82nd Annual meeting of the Transportation Research Board,* Washington, DC, 1-16.

El-Razek, M. E., Bassioni, H. A., and Mobarak, A. M. (2008). “Causes of delay in building construction projects in Egypt.” *Journal of Construction Engineering and Management, 134*(11), 831-841.

El-Wardani, M., Messner, J., and Horman, M. (2006). “Comparing procurement methods for design-build projects.” *Journal of Construction Engineering and Management, 132*(3), 230–238.

Enshassi, A., Al-Najjar, J., and Kumaraswamy, M. (2009). “Delays and cost overruns in the construction projects in the Gaza Strip.” *Journal of Financial Management of property and Construction, 14*(2), 126-151.

Eriksson, P. E. (2017). “Procurement strategies for enhancing exploration and exploitation in construction projects.” *Journal of Financial Management of property and Construction*, *22*(2), 211–230.

Farnsworth, C. B., Warr, R. O., Weidman, J. E., and Mark Hutchings, D. (2016). “Effects of CM/GC project delivery on managing process risk in transportation construction.” *Journal of Construction Engineering and Management, 142*(3), 04015091.

Famiyeh, S., Amoatey, C. T., Adaku, E., and Agbenohevi, C. S. (2017). “Major causes of construction time and cost overruns.” *Journal of Engineering, Design and Technology, 15*(2), 181–198.

Gardezi, S. S., Manarvi, I. A., and Gardezi, S. S. (2014). “Time extension factors in construction industry of Pakistan.” *Procedia Engineering,* 77, 196–204.

Golini, R., Matteo K., and Landoni, P. (2015). “Adoption of project management practices: The impact on international development projects of non-governmental organizations.” *International Journal of Project Management*, *33*(3), 650-663.

Gündüz, M., Nielsen, Y., and Özdemir, M. (2013). "Quantification of delay factors using the relative importance index method for construction projects in Turkey." *Journal of Management in Engineering, 29*(2), 133-139.

Hanna, A.S. (2012). "Using the earned value management system to improve electrical project control." *Journal of Construction Engineering and Management*, *138*(3), 449-457.

Hanna, A. S., Russell, J. S., Gotzion, T. W., and Nordheim, E. V. (1999). "Impact of change orders on labor efficiency for mechanical construction." *Journal of Construction Engineering and Management, 125*(3), 176-184.

Hale, D. R., Shrestha, P. P., Gibson Jr, G. E., and Migliaccio, G. C. (2009). "Empirical comparison of design/build and design/bid/build project delivery methods." *Journal of Construction Engineering and Management, 135*(7), 579-587.

Hatem, D. J. (1998). "Geotechnical baselines: professional liability implications." *Tunnelling and Underground Space Technology, 13*(2), 143-150.

Huang, Y., Shi, Q., Pena-Mora, F., Lu, Y., and Shen, C. (2020). "Exploring the impact of information and communication technology on team social capital and construction project performance." *Journal of Management in Engineering,* 36(5), 04020056.

Hurtado, K. C., Savicky, J., Sullivan, K. T., Smithwick, J. B., and Gajjar, D. (2018, April). "Construction portfolio management model for institutions." *Proceedings of the Construction Research Congress* (pp. 168-177). New Orleans, LA: ASCE.

Hurtado, K. C., Smithwick, J. B., Pesek, A. E., and Sullivan, K. T. (2017). "Public school facility underfunding: a new tool to maximize construction dollars and improve performance outcomes." *International Journal of Construction Education and Research, 14*(3), 218-231.

Hwang, B. G., Liao, P. C., and Leonard, M. P. (2011). “Performance and practice use comparisons: Public vs. Private owner projects.” *KSCE Journal of Civil Engineering, 15*(6), 957-963.

Hwang, B. G., Zhao, X., and Ng, S. Y. (2013). “Identifying the critical factors affecting schedule performance of public housing projects.” *Habitat International, 38*, 214-221.

Ibbs, W. (2005). “Impact of change’s timing on labor productivity.” *Journal of Construction Engineering and Management, 131*(11), 1219-1223.

Ibbs, W., Nguyen, L. D., and Lee, S. (2007). “Quantified impacts of project change.” Journal of *Professional Issues in Engineering Education and Practice, 133*(1), 45-52.

Ibbs, W., Kwak, Y. H., Ng, T., and Odabasi, A. M. (2003). “Project delivery systems and project change: Quantitative analysis.” *Journal of Construction Engineering and Management, 129*(4), 382-387.

Isa, M. F. M., and Usmen, M. (2015). “Improving university facilities services using Lean Six Sigma: a case study.” *Journal of Facilities Management, 13*(1), 70-84.

Javanmardi, A., Abbasian-Hosseini, S.A., Liu, M., and Hsiang, S.M. (2018). “Benefit of cooperation among subcontractors in performing high-reliable planning.” *Journal of Management in Engineering, 34*(2), 04017062.

Jiang, W., Lu, Y., and Le, Y. (2016). “Trust and project success: A twofold perspective between owners and contractors.” *Journal of Management in Engineering, International Journal of Project Management, 32*(6), 04016022.

Jung, M., Park, M., Lee, H. S., and Kim, H. (2016). “Weather-delay simulation model based on vertical weather profile for high-rise building construction.” *Journal of construction Engineering and Management, 142*(6), 04016007.

Kaming, P. F., Olomolaiye, P. O., Holt, G. D., and Harris, F. C. (1997). “Factors influencing construction time and cost overruns on high-rise projects in Indonesia.” *Construction Management and Economics, 15*(1), 83-94.

Koushki, P. A., Al-Rashid, K., and Kartam, N. (2005). “Delays and cost increases in the construction of private residential projects in Kuwait.” *Construction Management and Economics, 23*(3), 285- 294.

Kotb, M. H., and Ghattas. M. M. (2018). “Risk Identification Barriers in Construction Projects in MENA.” *PM World Journal, 7*(8), 1-16.

Larsen, J. K., Geoffrey, Q. S., Søren, M. L., and Thomas, D. B. (2016). "Factors affecting schedule delay, cost overrun, and quality level in public construction projects." *Journal of Management in Engineering, 32*(1), 04015032.

Lo, Y. T., Ivan, F. W, and Karen, T. C. (2006). “Construction delays in Hong Kong civil engineering projects.” *Journal of Construction Engineering and. Management, 132*(6), 636-649.

Lopez, R., and Love, P. E. D. (2012). “Design error costs in construction projects.” *Journal of Construction Engineering and Management, 138*(5), 585–593.

Long, N. D., Ogunlana, S., Quang, T., and Lam, K. C. (2004). “Large construction projects in developing countries: a case study from Vietnam.” *International Journal of Project Management,* 22(7), 553-561.

Love, P., Davis, P., Ellis, J., and Cheung, O. S. (2010). “Dispute causation: identification of pathogenic influences in construction.” *Engineering, Construction and Architectural Management, 17*(4), 404-423.

Mahat, N. A. A., and Adnan, H. (2018, November). "The influence of client brief and change order in construction project." *Proceedings of the IOP Conference Series: Earth and Environmental Science*, Shah Alam, Selangor, Malaysia: IOP Publishing.

Martens, A., and Vanhoucke, M. (2018). "An empirical validation of the performance of project control tolerance limits." *Automation in Construction*, *89*, 71-85.

Mir, F. A., and Pinnington, A. H. (2014). "Exploring the value of project management: linking project management performance and project success." *International Journal of Project Management, 32*(2), 202-217.

Moselhi, O. (2003). "Estimating the cost of change orders." *Cost Engineering, 45*(8), 24.

Moselhi, O., Assem, I., and El-Rayes, K. (2005). "Change orders impact on labor productivity." *Journal of Construction Engineering and. Management, 131*(3), 354-359.

Mossalam, A. (2018), "Projects' issue management." *HBRC Journal, 14*(3), 400-407.

Mossalam, A. (2020). "Developing a multi-criteria index for government projects performance." *HBRC Journal, 16*(1), 299-316.

National Center for Education Studies (2014). "Condition of America's Public School Facilities: 2012–13." Retrieved from http://nces.ed.gov/pubs2014/2014022.pdf.

Nguyen, P. H., Lines, B. C., and Tran, D. Q. (2018). "Best-value procurement in design-bid-build construction projects: Empirical analysis of selection outcomes." *Journal of Construction Engineering and Management, 144*(10), 04018093.

(NCES) National Center for Education Studies (2014). "Condition of America's Public School Facilities: 2012–13." Retrieved from http://nces.ed.gov/pubs2014/2014022.pdf

Odeck, J., (2004). "Cost overruns in road construction — what are their sizes and determinants?" *Transport Policy*, *11*(1), 43–53.

Odeh, A. M., and Battaineh, H. T. (2002). “Causes of construction delay: traditional contracts.” *International Journal of Project Management, 20*(1), 67-73.

Olawale, Y., and Ming, S. (2013). "PCIM: Project control and inhibiting-factors management model." *Journal of Management in Engineering, 29*(1), 60-70.

Olawale, Y., and Sun, M. (2010). “Cost and time control of construction projects: inhibiting factors and mitigating measures in practice.” *Construction Management and Economics, 28*(5), 509-526.

Orgut, R.E., Batouli, M., Zhu, J., Mostafavi, A., and Jaselskis, E. J. (2020). “Critical factors for improving reliability of project control metrics throughout project life cycle.” *Journal of Management in Engineering, 36*(1), 04019033.

Orgut, R. E., Mostafa, B., Jin, Z., Ali, M., and Edward, J. J. (2020). "Critical factors for improving reliability of project control metrics throughout project life cycle." *Journal of Management in Engineering*, *36*(1): 04019033.

Papke-Shields, K. E., and Boyer-Wright, K. M. (2017). “Strategic planning characteristics applied to project management.” *International Journal of Project Management*, 35(2), 169-179.

Park, H. S., Lee, D., Kim, S., and Kim, J. L. (2015). “Comparing project performance of design-build and design-bid-build methods for large-sized public apartment housing projects in Korea.” *Journal of Asian Architecture and Building Engineering, 14*(2), 323-330.

Perrenoud, A., Lines, C. B., and Sullivan, T. K. (2014). “Measuring risk management performance within a capital program.” *Journal of Facilities Management, 12*(2), 158-171.

Perrenoud, A., Lines, B. C., Savicky, J., and Sullivan, K. (2017). “Using Best Value Procurement to Measure the Impact of Initial Risk Management Capability to Qualitative Construction Performance.” *ASCE Journal of Management in Engineering*, 33(5). DOI:10.1061/(ASCE)ME.1943.

Pesek, A. E., Smithwick, J. B., Saseendran, A., and Sullivan, K. T. (2019). “Information Asymmetry on Heavy Civil Projects: Deficiency Identification by Contractors and Owners.” *Journal of Management in Engineering, 35*(4), 04019008.

Pocock, J. B., Hyun, C. T., Liu, L. Y., and Kim, M. K. (1996). “Relationship between project interaction and performance indicators.” *Journal of Construction Engineering and Management, 122*(2), 165-176.

Prasad, K.V., and Venkatesan, V. (2017). “Delays in construction projects: A review of causes, need and scope for further research.” *Malaysian Construction Research Journal, 23*(3), 89-113.

Project Management Institute (PMI). (2017). “A Guide to the Project Management Body of Knowledge (PMI® Guide 6th Edition)”. Newtown Square, PA: Project Management Institute, Inc.

Rodríguez-Labajos, L., Thomson, C., and O’Brien, G. (2018). “Performance measurement for the strategic management of health-care estates.” *Journal of Facilities Management, 16*(2), 217-232.

Rojas, E. M., and Kell, I. (2008). “Comparative analysis of project delivery systems cost performance in Pacific Northwest public schools.” *Journal of Construction Engineering and Management, 134*(6), 387-397.

Rosner, J. W., Thal Jr, A. E., and West, C. J. (2009). "Analysis of the design-build delivery method in air force construction projects." *Journal of Construction Engineering and Management, 135*(8), 710-717.

Safapour, E., and Kermanshachi, S. (2019). "Identifying early indicators of manageable rework causes and selecting mitigating best practices for construction." *Journal of Management in Engineering, 35*(2), 04018060.

Salehipour, A., Naeni, L.M., Khanbabaei, R., and Javaheri, A. (2016). "Lessons learned from applying the individuals control charts to monitoring autocorrelated project performance data." *Journal of Construction Engineering and Management, 142*(5), 04015105.

Sambasivan, M., and Soon, Y. W. (2007). "Causes and effects of delays in Malaysian construction industry." *International Journal of Project Management, 25*(5), 517-526.

Santoso, D.S., and Soeng, S. (2016). "Analyzing delays of road construction projects in Cambodia: Causes and effects." *Journal of Management in Engineering, 32*(6), 05016020.

Serag, E., Oloufa, A., Malone, L., and Radwan, E. (2010). "Model for quantifying the impact of change orders on project cost for US roadwork construction." *Journal of Construction Engineering and Management*, *136*(9), 1015-1027.

Shahin, A., AbouRizk, S. M., and Mohamed, Y. (2011). "Modeling weather-sensitive construction activity using simulation." *Journal of Construction Engineering and Management, 137*(3), 238-246.

Shalwani, A., and Lines, B.C. (2020). "An empirical analysis of issue management in small building construction projects." *International Journal of Construction Education and Research*, 1–21.

Shdid, C. A., Andary, E., Chowdhury, A. G., and Ahmad, I. U. (2019). “Project performance rating model for water and wastewater treatment plant public projects.” *Journal of Management in Engineering, 35*(2), 04018064.

Shehu, Z., Endut, I. R., Akintoye, A., and Holt, G. D. (2014). “Cost overrun in the Malaysian construction industry projects: A deeper insight.” *International Journal of Project Management, 32*(8), 1471-1480.

Shohet, I. M., and Frydman, S. (2003). “Communication patterns in construction at construction manager level.” *Journal of Construction Engineering and Management, 129*(5), 570-577.

Shrestha, P. P., and Maharjan, R. (2018). “Effects of change orders on cost growth, schedule growth, and construction intensity of large highway projects.” *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 10*(3), 04518012.

Siraj, N.B., and Fayek, A.R. (2019). “Risk identification and common risks in construction: Literature review and content analysis.” *Journal of Construction Engineering and Management*, *145*(9), 03119004.

Sullivan, K. (2011). “Quality management programs in the construction industry: Best value compared with other methodologies.” *Journal of Management in Engineering, 27*(4), 210-219.

Sullivan, K., Georgoulis S. W., and Lines, B. C. (2010). “Empirical study of the current United States facilities management profession.” *Journal of Facilities Management, 8*(2), 91-103.

Sullivan, K., and McDonald, D.K. (2011). “Leadership Principles and Performance Measurement in Facilities Management: A Case Study.” *Leadership and Management in Engineering*, *11*(4), 302-309.

Sun, M., and Meng, X. (2009). "Taxonomy for change causes and effects in construction projects." *International Journal of Project Management, 27*(6), 560-572.

Sweis, G., Sweis, R., Hammad, A. A., and Shboul, A., (2008). "Delays in construction projects: The case of Jordan." *International Journal of Project Management, 26*(6), 665-674.

Tereso, A., Ribeiro, P., Fernandes, G., Loureiro, I., and Ferreira, M., (2019). "Project management practices in private organizations." *Project Management Journal*, *50*(1), 6-22.

Thiry, M. (2015). "Program Management." Ashgate Publishing, Ltd.

Thomas, S. R., Macken, C. L., Chung, T. H., and Kim, I. (2002). "Measuring the impacts of the delivery system on project performance design-build and design-bid-build." *NIST GCR, 2,* 840.

Tuckman, B.W., and Jensen, M.A.C. (1977). "Stages of Small-Group Development Revisited", *Group and Organization Studies*, *2*(4), 419-427.

Uhlik, F. T., and Eller, M. D. (1999). "Alternative delivery approaches for military medical construction projects." *Journal of Architectural Engineering, 5*(4), 149-155.

Wang, J., and Yuan, H. (2017). "System dynamics approach for investigating the risk effects on schedule delay in infrastructure projects." *Journal of Management in Engineering, 33*(1), 04016029.

Wiguna, I. P. A., and Scott, S. (2006). "Relating risk to project performance in Indonesian building contracts." *Construction Management and Economics*, *24*(11), 1125-1135.

Williams, G. H. (2003). "An evaluation of public construction contracting methods for the public building sector in Oregon using data envelopment analysis (Doctoral dissertation)." Portland State University, Portland, OR.

Yiu, T.W., Keung, C.W., and Wong, L.K. (2011). “Application of equity sensitivity theory to problem-solving approaches in construction dispute negotiation.” *Journal of Management in Engineering, 27*(1), 40–47.

APPENDICES

APPENDIX A – SUPPLEMENTAL INFORMATION FOR CHAPTER 2

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Table A1. Sub-Hypothesis Statements for the Main Hypothesis for Chapter 2

Chapter	Hypothesis	Statement
2	H2a	The eight issue types are identified at different points of time during the construction phase
	H2b	The eight issue types are resolved at different points of time during the construction phase

NO	DATE IDENTIFIED	ISSUE TYPE	ISSUE DESCRIPTION	COST IMPACT	SCHEDULE IMPACT	PLANNED RESOLUTION DATE	ACTUAL DATE RESOLVED
0	1/15/11	Please identify the party responsible for the issue from the drop down menu	Please describe the details of the issue occurred: 1. What is the Issue / why was it unexpected? 2. What will be done / what is plan to minimize this Issue? 3. Who is responsible for resolving the issue? 4. What kind of impact will this have? 5. Any updates to this issue (if applicable)	15	10000	2/15/11	2/1/11
1			1.				
2			1.				

Figure A1. Issue Log Template

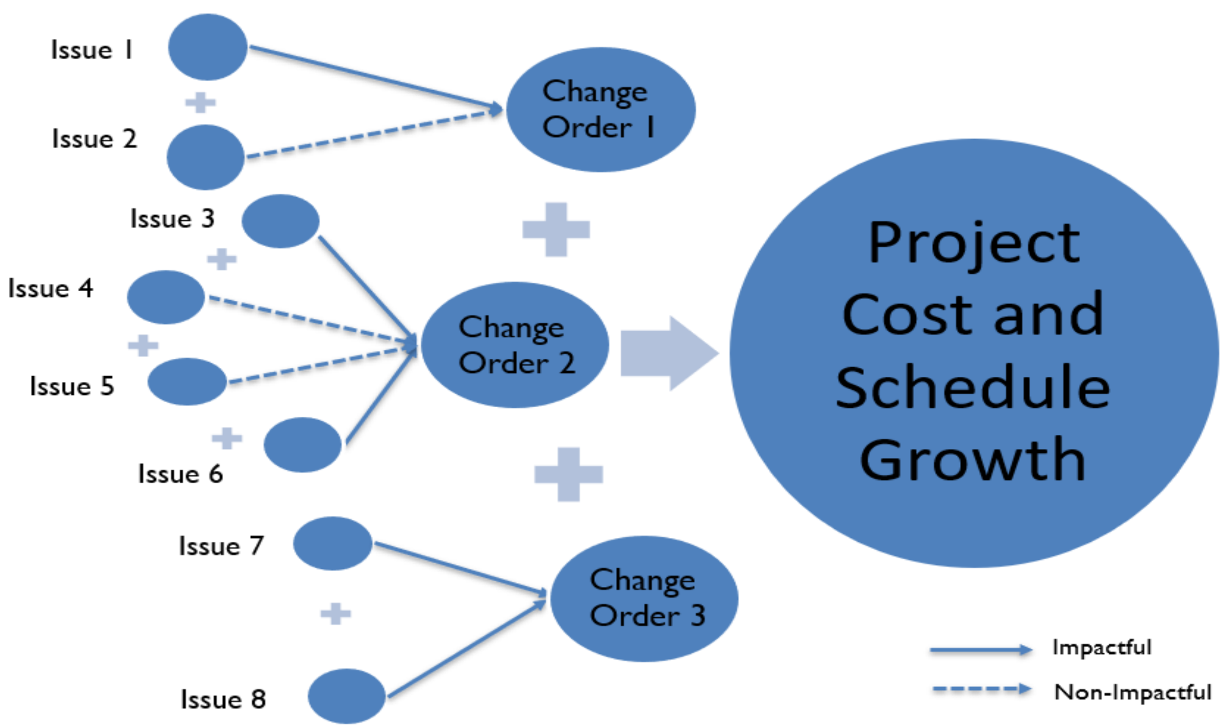

Figure A2. Evolution of Individual Issues to Change Orders to Project Cost and Schedule Growth

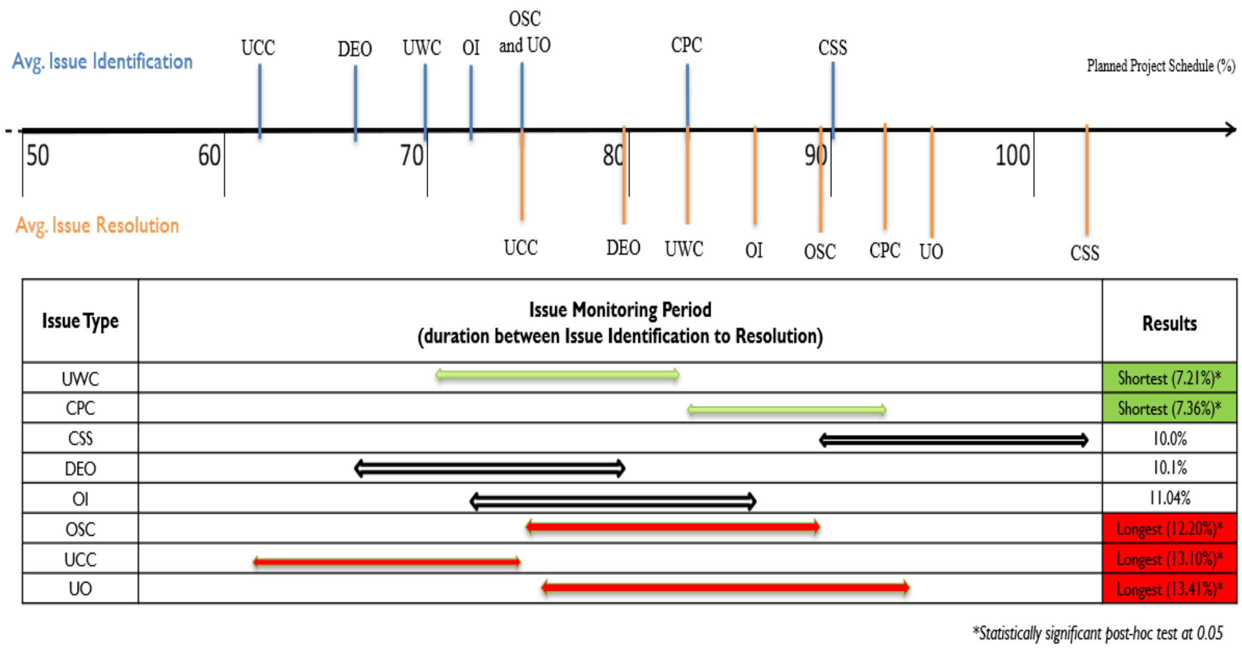

Figure A3. Average Issue Identification, Resolution, and Monitoring Period for Different Issue Types on Planned Project Schedule (%)

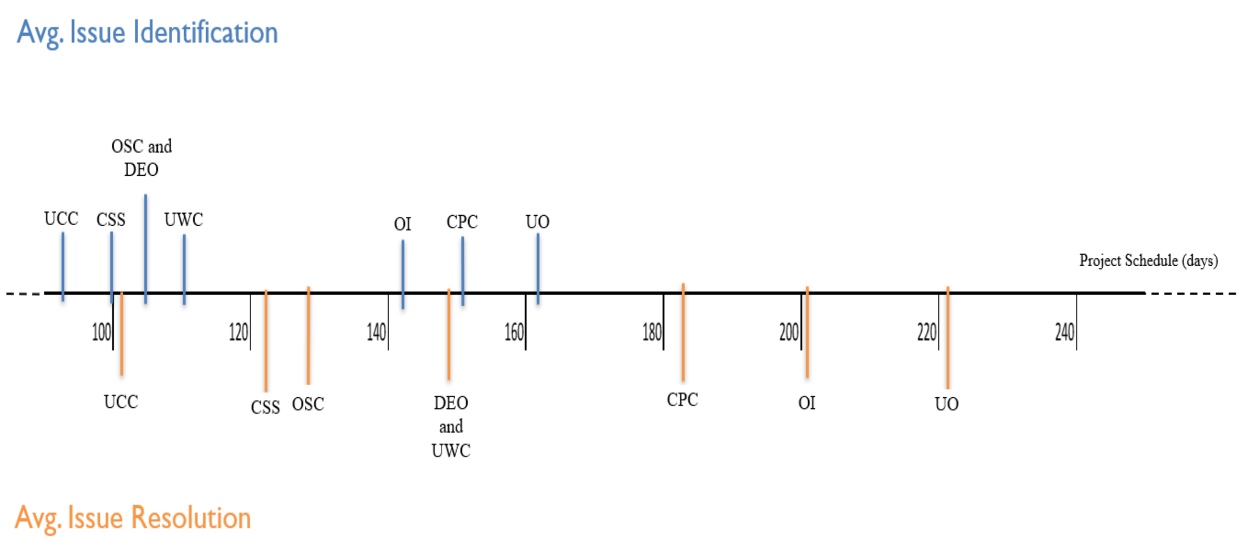

Figure A4. Average Issue Identification and Resolution for Different Issue Types on Planned Project Schedule (%)

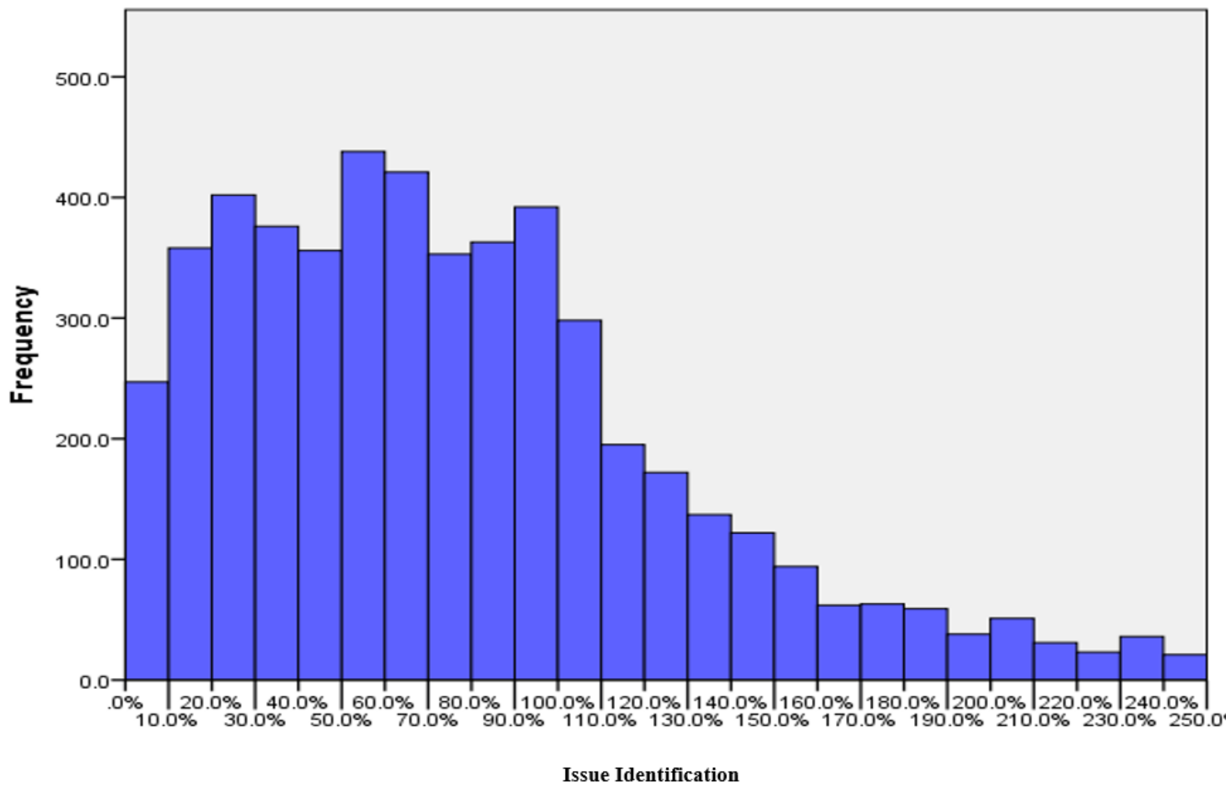

Figure A5. Frequency Analysis of Issue Identification for the Project Sample Size

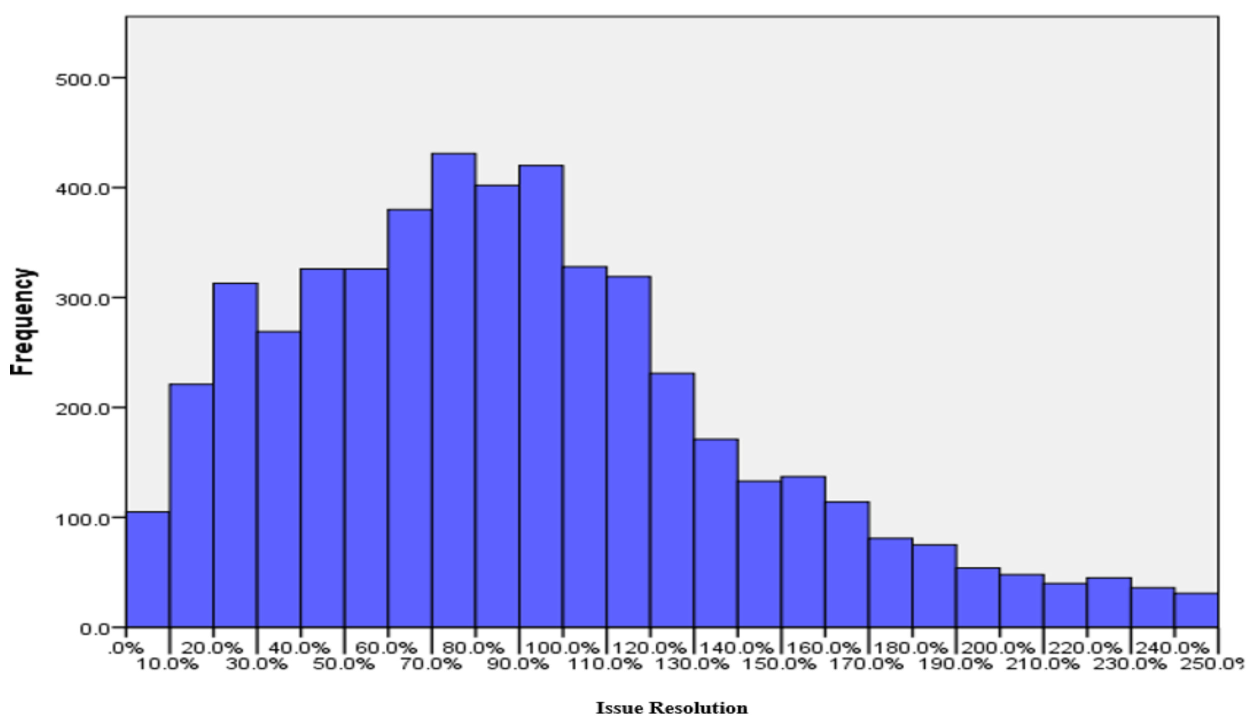

Figure A6. Frequency Analysis of Issue Resolution for the Project Sample Size

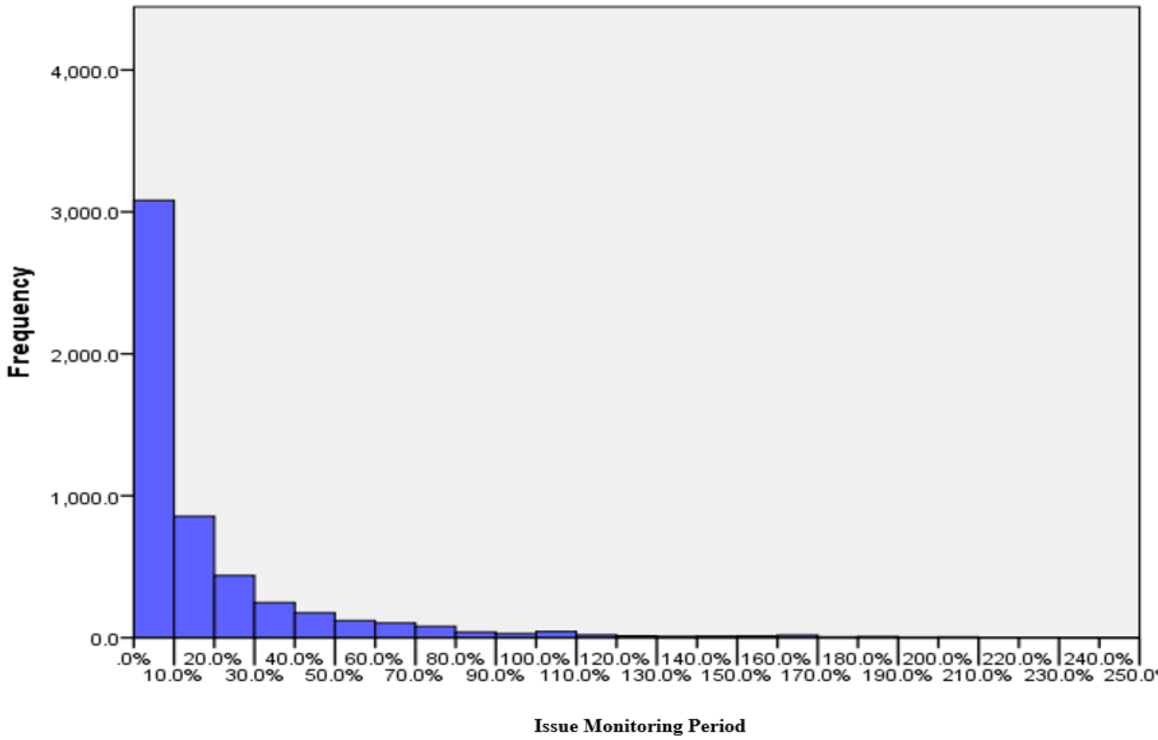

Figure A7. Frequency Analysis of Issue Monitoring Period for the Project Sample Size

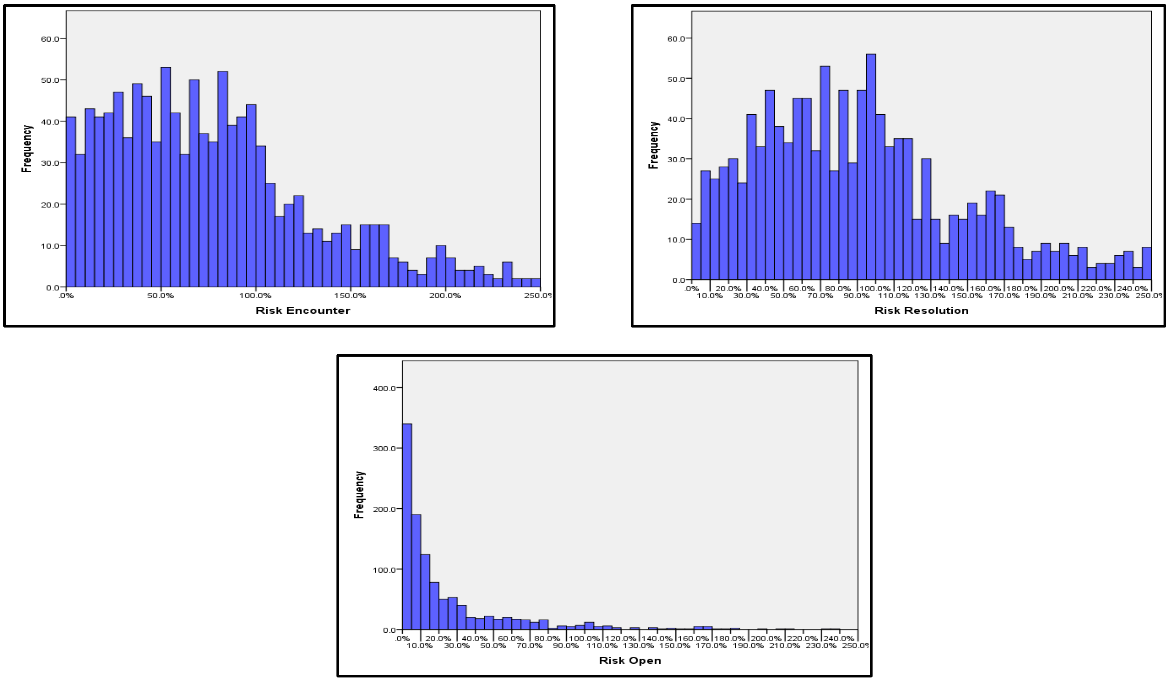

Figure A8. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for the Owner – Internal Issus

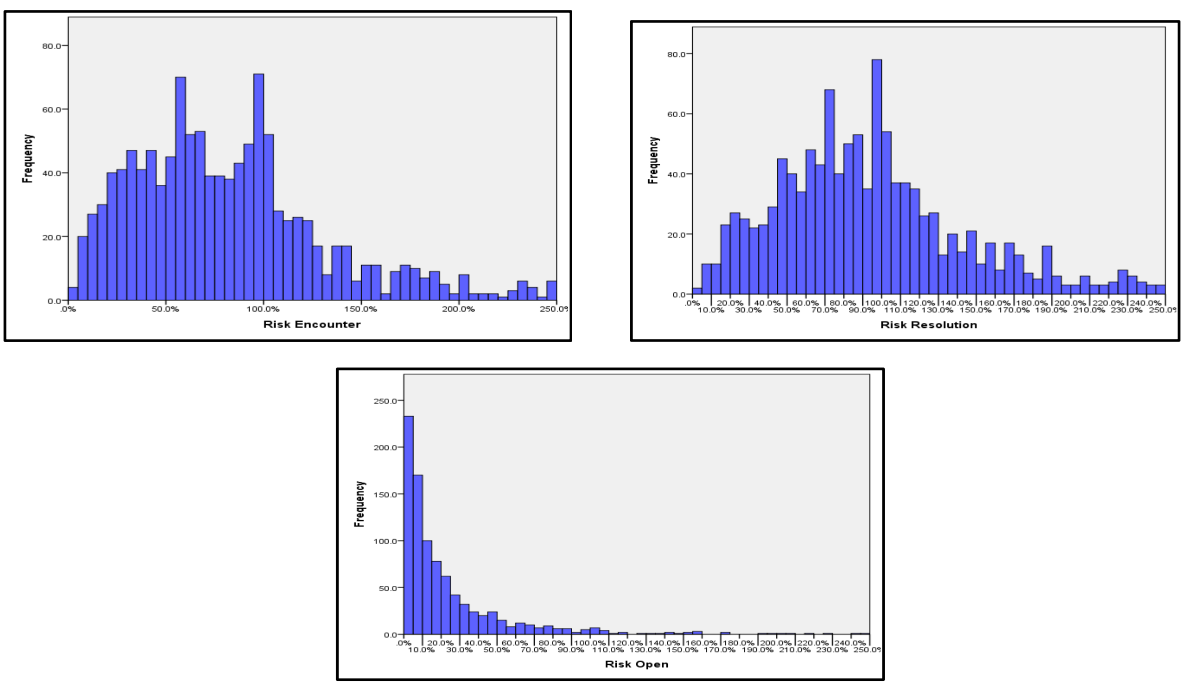

Figure A9. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for the Owner – Scope Change Issues

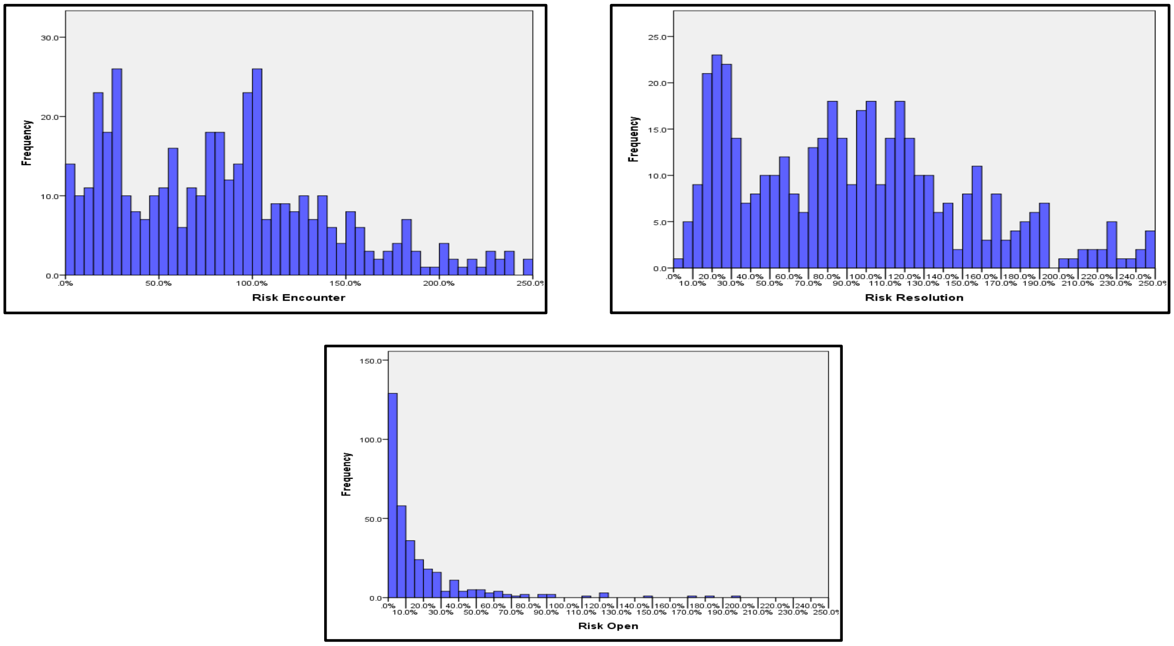

Figure A10. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for the Contractor – Prime Contractor Issues

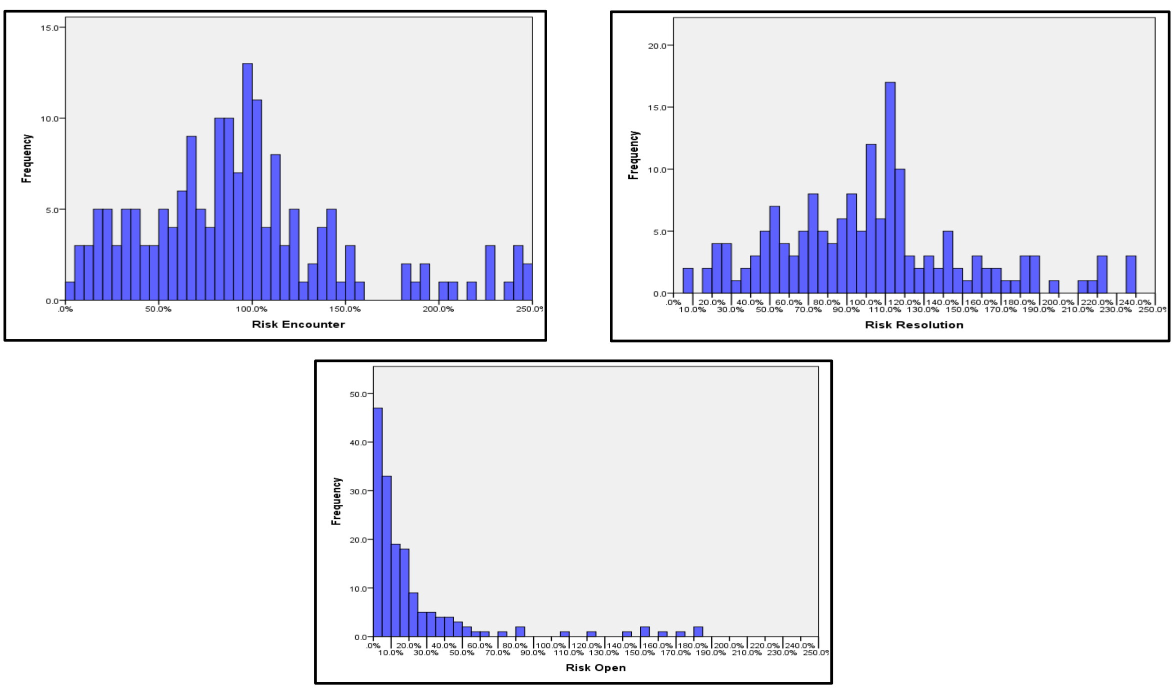

Figure A11. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for the Contractor – Subcontractor and Supplier Issues

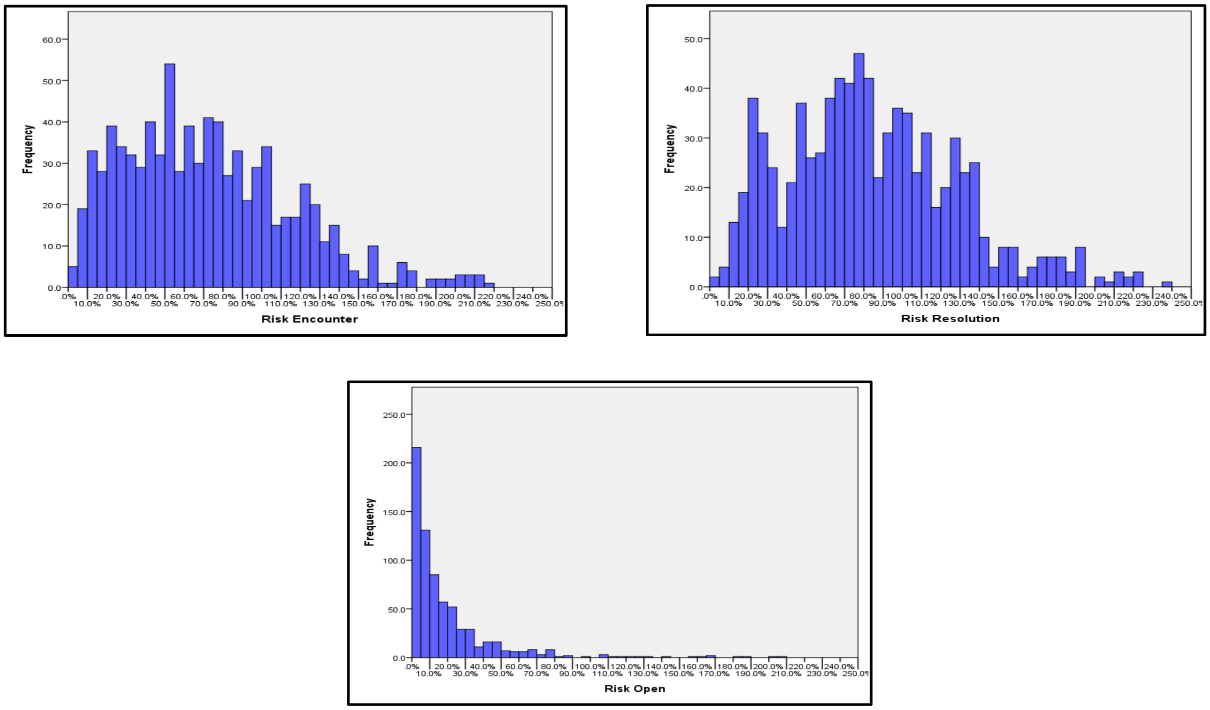

Figure A12. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for Designer – Errors and Omissions

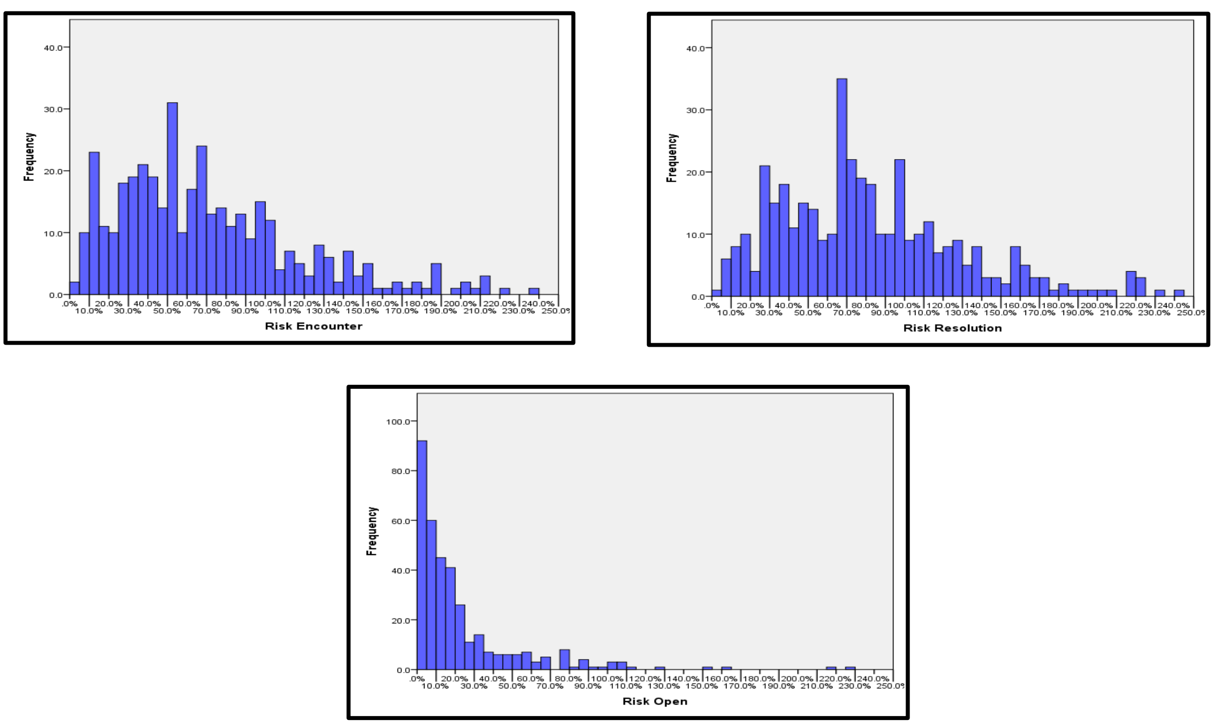

Figure A13. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for Unforeseen – Concealed Conditions Issues

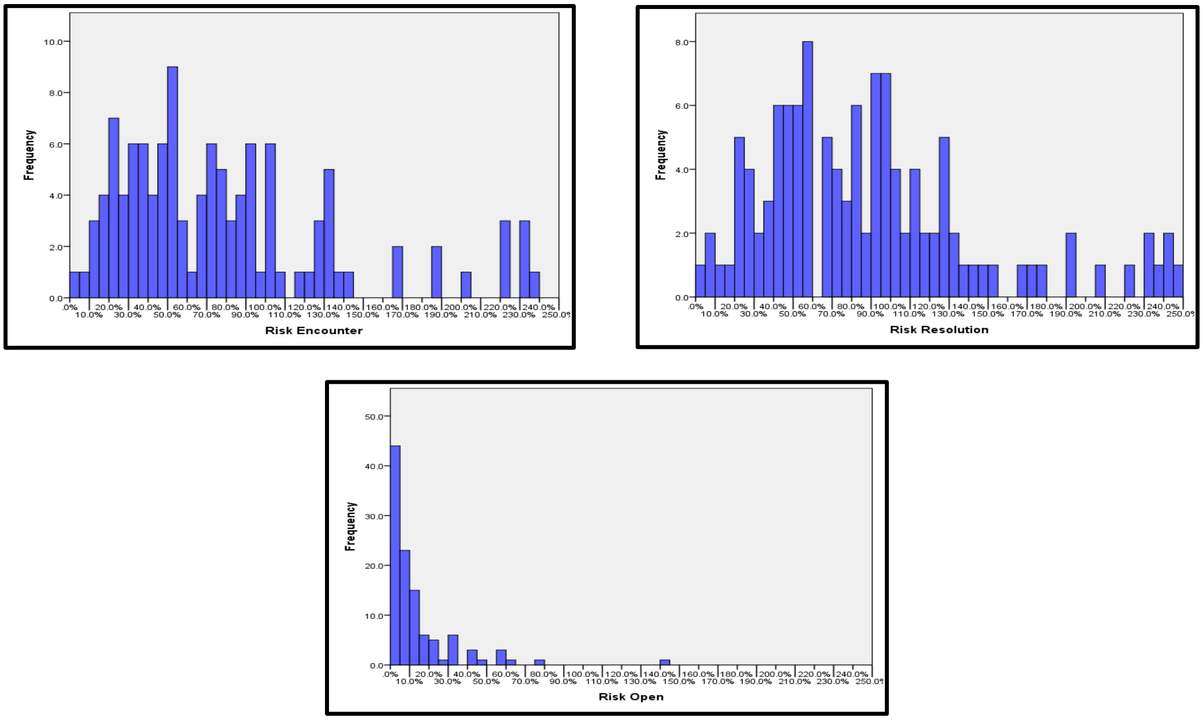

Figure A14. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for Unforeseen – Weather Conditions Issues

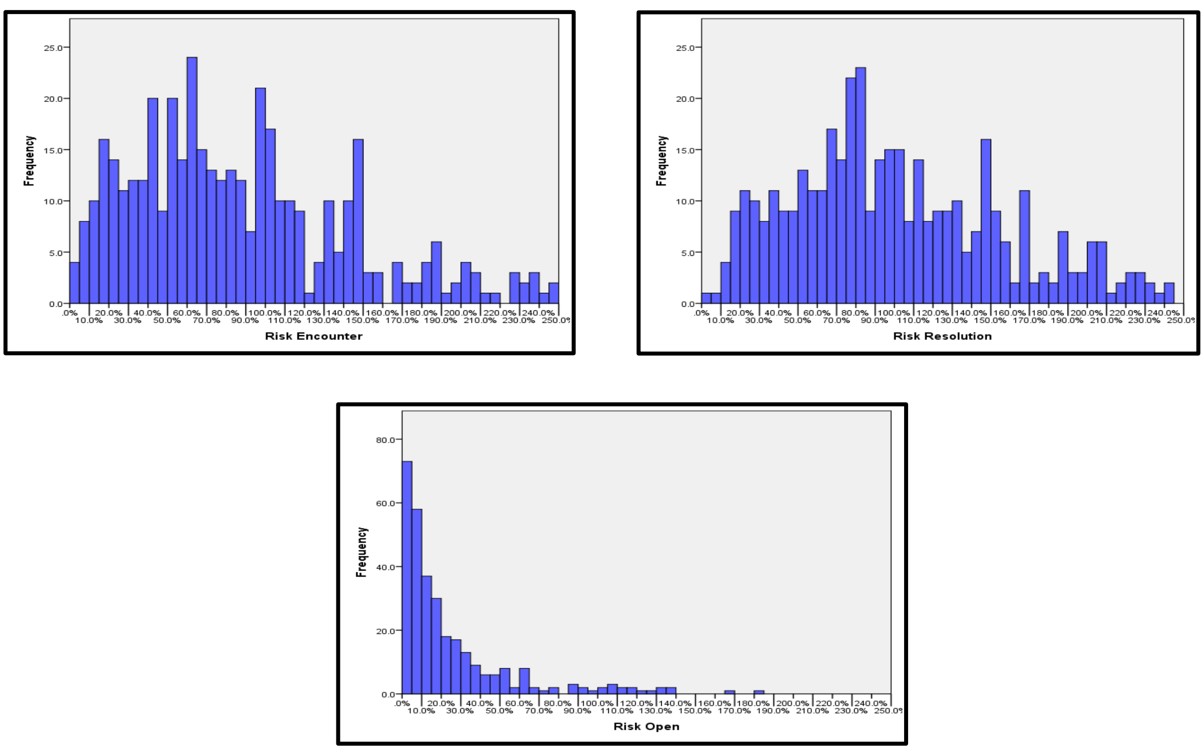

Figure A15. Frequency Analysis of Issue Identification, Resolution, and Monitoring Period for Unforeseen – Other Issues

APPENDIX B – SUPPLEMENTAL INFORMATION FOR CHAPTER 3

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Table B1. Cumulative Awarded, Completed, and Cost Growth for Project Sample Size

Project Size	N	Sum	Mean	Median	Std. Deviation	Minimum	Maximum
Awarded Cost ($)							
Large	276	$953,047,176	$3,453,069	$2,377,540	$3,386,657	$1,082,072	$25,987,230
Medium	277	$190,811,155	$688,849	$660,471	$167,513	$430,800	$1,067,790
Small	328	$77,448,701	$236,124	$249,617	$125,564	$12,890	$430,600
Total	881	$1,221,307,032	$1,386,274	$635,781	$2,363,212	$12,890	$25,987,230
Completion Cost ($)							
Large	276	$1,002,274,772	$3,631,430	$2,498,357	$3,510,890	$916,071	$26,706,287
Medium	277	$206,224,139	$744,491	$719,972	$229,763	$434,638	$2,332,164
Small	328	$85,276,976	$259,991	$271,880	$143,338	$12,390	$709,247
Total	881	$1,293,775,887	$1,468,531	$674,002	$2,460,247	$12,390	$26,706,287
Total Project Cost Impact to USD ($)							
Large	276	$49,232,900	$178,380.07	$57,767.00	$267,972.18	($212,889)	$1,357,070
Medium	277	$15,425,484	$55,687.67	$11,967.00	$130,280.36	($204,784)	$1,325,399
Small	328	$7,828,311	$23,866.80	$4,464.21	$44,629.50	($53,013)	$278,647
Total	881	$72,486,695	$82,277.75	$11,840.54	$181,368.94	($212,889)	$1,357,070

Table B2. Cumulative Awarded, Completed, and Schedule Growth for Project Sample Size

Project Size	N	Sum	Mean	Median	Std. Deviation	Minimum	Maximum
Planned Project Duration (Days)							
Large	275	170010	618.22	403	2365.272	81	39431
Medium	272	156792	576.44	271	3343.025	13	39407
Small	310	242841	783.36	121	4929.25	2	39388
Total	857	569643	664.69	264	3756.078	2	39431
Actual Project Duration (Days)							
Large	276	224589	813.73	582	2362.141	105	39448
Medium	277	192345	694.39	351	3316.88	37	39448
Small	327	265992	813.43	136	4799.911	3	39408
Total	880	682926	776.05	352.5	3707.807	3	39448
Total Project Schedule Impact (Days)							
Large	276	54764	198.42	114.5	243.541	-105	1378
Medium	277	35753	129.07	65	183.558	-196	1161
Small	328	23791	72.53	21	137.063	-163	943
Total	881	114308	129.75	57	196.933	-196	1378

Table B3. Descriptive of Cost Impact for Different Issue Types

Issue Type	N	Mean	Median	Std. Deviation	Minimum	Maximum
For small projects (<$375k)						
OI	130	5.10%	0.0%	12.4%	-13.3%	179.9%
OSC	148	11.00%	4.0%	12.8%	-7.6%	133.3%
CPC	32	0.00%	0.0%	0.6%	-0.3%	4.1%
CSS	44	0.30%	0.0%	1.5%	-4.3%	9.1%
DEO	76	4.50%	1.3%	5.5%	-6.2%	35.4%
UCC	52	3.20%	1.7%	3.7%	-7.9%	31.4%
UWC	18	0.60%	0.0%	1.2%	-0.6%	4.7%
UO	37	3.20%	0.0%	9.0%	-0.5%	57.1%
For medium projects (<$375k - $1M)						
OI	161	3.10%	0.0%	5.1%	-6.5%	47.9%
OSC	108	7.80%	2.3%	7.0%	-11.3%	53.3%
CPC	92	1.20%	0.0%	3.7%	-3.9%	30.3%
CSS	40	0.20%	0.0%	14.2%	-0.9%	99.1%
DEO	57	5.10%	0.7%	7.6%	-0.8%	103.2%
UCC	59	4.10%	1.0%	4.9%	-0.4%	36.0%
UWC	16	0.10%	0.0%	0.1%	0.0%	0.6%
UO	82	3.70%	0.0%	10.0%	-30.0%	107.7%
For large projects (<$1M - $5M)						
OI	144	3.10%	0.0%	2.9%	-10.6%	26.7%
OSC	112	6.50%	1.9%	5.7%	-19.8%	99.7%
CPC	79	0.40%	0.0%	2.5%	-8.0%	37.2%
CSS	31	3.20%	0.0%	0.1%	0.0%	0.3%
DEO	55	1.80%	0.9%	0.7%	-1.4%	10.7%
UCC	65	2.10%	0.6%	2.2%	-0.8%	16.5%
UWC	35	0.10%	0.0%	0.2%	0.0%	1.2%
UO	90	2.70%	0.0%	4.0%	-2.8%	34.5%

Table B4. Descriptive of Schedule Impact for Different Issue Types

Issue Type	N	Mean	Median	Std. Deviation	Minimum	Maximum
For small projects (<$375k)						
OI	116	36.00%	15.20%	135.01%	-1400.00%	545.45%
OSC	135	24.00%	3.90%	69.71%	-487.50%	693.33%
CPC	32	-1.10%	0.00%	29.49%	-45.06%	125.41%
CSS	42	16.80%	0.00%	234.39%	-285.71%	2250.00%
DEO	74	18.00%	0.00%	46.65%	-200.00%	340.99%
UCC	51	13.70%	0.00%	36.04%	-315.79%	206.90%
UWC	18	12.40%	0.00%	30.34%	-48.65%	142.86%
UO	37	9.50%	0.00%	42.97%	-39.74%	306.38%
For medium projects (<$375k - $1M)						
OI	153	40.90%	24.40%	51.08%	-125.00%	618.92%
OSC	101	28.20%	2.00%	46.30%	-214.29%	346.15%
CPC	90	14.80%	0.00%	22.47%	-54.32%	140.50%
CSS	37	8.60%	0.00%	49.30%	-281.82%	144.37%
DEO	54	13.30%	0.00%	24.93%	-190.91%	110.53%
UCC	58	6.90%	0.00%	9.35%	-50.00%	48.00%
UWC	16	0.90%	0.00%	53.26%	-6.25%	261.54%
UO	79	21.60%	4.60%	35.82%	-55.08%	248.34%
For large projects ($1M - $5M)						
OI	141	39.70%	21.30%	24.83%	-32.43%	239.85%
OSC	110	22.50%	4.20%	17.39%	-62.70%	239.85%
CPC	79	8.10%	0.00%	15.24%	-35.91%	95.08%
CSS	31	7.60%	0.00%	5.32%	-19.61%	22.14%
DEO	54	9.80%	0.00%	5.62%	0.00%	67.59%
UCC	64	8.10%	0.00%	10.71%	-1.76%	89.86%
UWC	35	13.30%	0.00%	10.49%	0.00%	77.89%
UO	90	15.40%	2.80%	16.57%	-21.86%	138.21%

Table B5. Descriptive of Cost Impact for Projects with Different Number of Issues

		Total Project Cost Growth (%)				
# of Issues	**N**	**Mean**	**Median**	**Std. Deviation**	**Minimum**	**Maximum**
1	186	3.39%	0.00%	9.39%	-1.37%	72.87%
2	144	5.86%	0.45%	12.63%	-11.90%	88.19%
3	107	9.25%	2.85%	17.20%	-4.38%	133.33%
4	86	10.55%	1.90%	21.04%	-5.24%	132.37%
5	72	10.50%	5.00%	16.12%	-6.47%	86.87%
6	49	11.43%	3.99%	25.19%	-6.47%	161.28%
7	41	13.94%	6.57%	23.92%	-4.33%	131.65%
8	28	7.43%	5.59%	8.71%	0.00%	34.97%
9	19	8.49%	6.54%	10.06%	-3.76%	34.76%
10	19	4.74%	3.58%	13.41%	-31.58%	28.43%
11	12	23.20%	5.55%	53.15%	0.00%	189.77%
12	14	7.59%	6.07%	8.33%	-2.47%	26.16%
13	16	13.94%	4.74%	18.31%	-5.85%	57.23%
14	6	6.52%	3.97%	8.40%	0.37%	23.06%
15	6	12.45%	14.15%	5.56%	4.13%	18.64%
16	7	12.35%	12.57%	10.27%	0.83%	27.34%
17	9	20.13%	19.03%	15.62%	0.00%	43.46%
18	4	8.26%	6.46%	7.50%	2.18%	17.93%
19	5	5.43%	5.12%	11.16%	-7.38%	22.85%
20	5	9.52%	7.28%	8.44%	1.77%	23.46%
21	4	15.08%	14.47%	3.92%	10.99%	20.38%
22	4	4.78%	3.34%	5.58%	-0.31%	12.75%
23	4	39.59%	25.60%	62.30%	-15.52%	122.68%
24	4	4.18%	3.82%	4.41%	-0.40%	9.46%
25	30	10.55%	6.76%	12.60%	-0.53%	64.71%
Total	881	8.38%	2.45%	17.25%	-31.58%	189.77%

Table B6. Descriptive of Schedule Impact for Projects with Different Number of Issues

# of Issues	N	Total Project Schedule Impact (%) Mean	Median	Std. Deviation	Minimum	Maximum
1	186	32.97%	2.41%	170.81%	-55.08%	2250.00%
2	144	41.50%	23.04%	108.17%	-850.00%	682.98%
3	107	21.64%	27.74%	222.12%	-1400.00%	893.33%
4	86	76.60%	35.13%	173.36%	-473.68%	738.46%
5	72	70.60%	38.27%	178.01%	-871.43%	779.34%
6	49	71.64%	41.12%	135.20%	-371.43%	564.71%
7	41	74.89%	33.33%	86.50%	0.00%	301.48%
8	28	121.82%	77.88%	177.72%	0.00%	863.64%
9	19	33.72%	43.04%	218.56%	-727.27%	368.29%
10	19	86.10%	70.42%	116.52%	-2.35%	428.41%
11	12	45.24%	27.89%	122.91%	-245.10%	230.00%
12	14	61.09%	55.30%	159.32%	-340.63%	430.39%
13	16	39.12%	21.45%	54.64%	-0.99%	219.94%
14	6	155.13%	112.00%	147.85%	2.51%	332.70%
15	6	102.42%	58.01%	343.54%	-348.00%	714.29%
16	7	55.62%	44.91%	58.72%	0.00%	130.56%
17	9	-131.63%	0.00%	753.23%	-2100.00%	381.72%
18	4	11.29%	11.97%	8.61%	0.38%	20.84%
19	5	43.68%	52.19%	24.22%	1.33%	61.11%
20	5	42.23%	34.32%	33.22%	0.00%	78.44%
21	4	127.24%	32.92%	210.57%	1.00%	442.11%
22	4	80.92%	15.33%	134.76%	10.00%	283.03%
23	4	43.48%	34.31%	38.35%	7.75%	97.54%
24	4	29.66%	29.07%	29.79%	0.00%	60.53%
>25	30	6.13%	5.56%	133.03%	-521.43%	283.03%
Total	881	48.72%	22.50%	177.40%	-2100.00%	2250.00%

Table B7. Descriptive Analysis of Issue Identification and Resolution Across Issue Types (Days)

Issue Type	Number of Issues	Mean	Median	Std. Dev.	Minimum	Maximum
Issue Identification						
OI	972	171	147	122	2	450
OSC	1122	139	107	109	2	448
CPC	786	152	114	117	1	447
CSS	297	175	153	123	2	450
DEO	171	134	102	106	8	421
UCC	370	107	78	96	3	448
UWC	96	146	108	110	9	433
UO	278	178	165	115	1	450
Issue Resolution						
OI	972	218	200	136	2	549
OSC	1122	169	128	125	4	550
CPC	786	182	143	127	1	541
CSS	297	205	185	130	7	538
DEO	171	160	117	118	13	500
UCC	370	135	99	113	4	525
UWC	96	182	146	119	17	513
UO	278	232	227	130	1	525

Table B8. Descriptive Analysis of Issue Monitoring Period of Issues Across Issue Types (Days)

Issue Type	Number of Issues	Mean	Median	Std. Dev.	Minimum	Maximum
OI	972	47	21	69	0	494
OSC	1122	30	10	51	0	373
CPC	786	30	14	45	0	432
CSS	297	31	13	46	0	280
DEO	171	26	14	38	0	365
UCC	370	27	11	48	0	455
UWC	96	36	14	58	0	270
UO	278	54	25	79	0	431

Table B9. Sub-Hypothesis Statements for the Main Hypothesis for Chapter 3

Chapter	Hypothesis	Statement
	H4a	Project sizes have a significant impact on cost growth
	H4b	Project sizes have a significant impact on schedule growth
	H5a	Different issue types have a different impact on cost growth
	H5b	Different issue types have a different impact on schedule growth
	H6a	Different issue types have different impact on cost growth for project size of <$375k
	H6b	Different issue types have different impact on cost growth for project size of <$375k - $1M
	H6c	Different issue types have different impact on cost growth for project size of $1M - $5M
	H6d	Different issue types have different impact on schedule growth for project size of <$375k
	H6e	Different issue types have different impact on schedule growth for project size of <$375k - $1M
	H6f	Different issue types have different impact on schedule growth for project size of $1M - $5M
	H7a	Owner - Internal issues have a significant impact on cost growth for different project sizes
	H7b	Owner - Internal issues have a significant impact on schedule growth for different project sizes
	H7c	Owner - Scope Change issues have a significant impact on cost growth for different project sizes
	H7d	Owner - Scope Change have a significant impact on schedule growth for different project sizes
	H7e	Contractor - Prime Contractor issues have a significant impact on cost growth for different project sizes
	H7f	Contractor - Prime Contractor issues have a significant impact on schedule growth for different project sizes
	H7g	Contractor - Subcontractor and Supplier issues have a significant impact on cost growth for different project sizes
3	H7h	Contractor - Subcontractor and Supplier issues have a significant impact on schedule growth for different project sizes
	H7i	Designer - Errors and Omissions issues have a significant impact on cost growth for different project sizes
	H7j	Designer - Errors and Omissions issues have a significant impact on schedule growth for different project sizes
	H7k	Unforeseen - Concealed Conditions issues have a significant impact on cost growth for different project sizes
	H7l	Unforeseen - Concealed Conditions issues have a significant impact on schedule growth for different project sizes
	H7m	Unforeseen - Weather Conditions issues have a significant impact on cost growth for different project sizes
	H7n	Unforeseen - Weather Conditions issues have a significant impact on schedule growth for different project sizes
	H7o	Unforeseen - Other issues have a significant impact on cost growth for different project sizes
	H7p	Unforeseen - Other issues have a significant impact on schedule growth for different project sizes
	H9d	Project teams tend to use a consistent level of IMI in the 4th quartile of the project schedule duration for projects with a cost growth
	H9e	Project teams tend to use a consistent level of IMI in the 1st quartile of the project schedule duration for projects with a schedule growth
	H9f	Project teams tend to use a consistent level of IMI in the 2nd quartile of the project schedule duration for projects with a schedule growth
	H9g	Project teams tend to use a consistent level of IMI in the 3rd quartile of the project schedule duration for projects with a schedule growth
	H9h	Project teams tend to use a consistent level of IMI in the 4th quartile of the project schedule duration for projects with a schedule growth

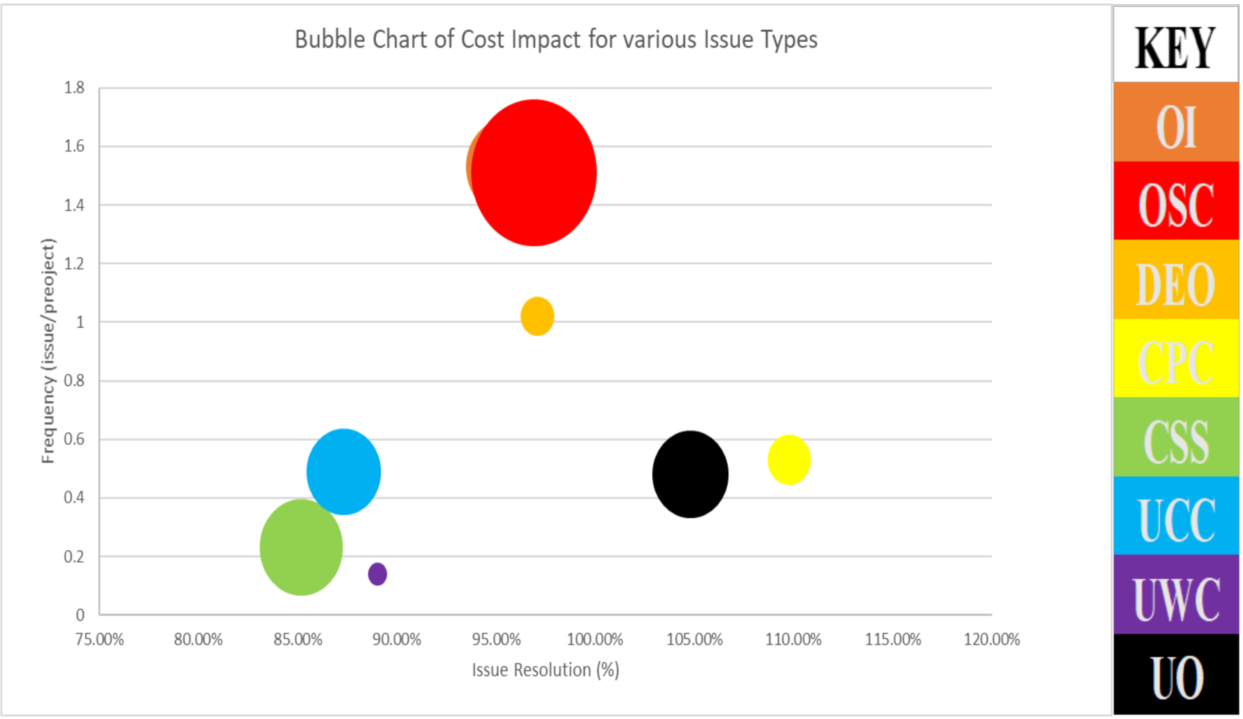

Figure B1. Bubble Chart of Cost Impact by Issue Types and Average Issue Resolution

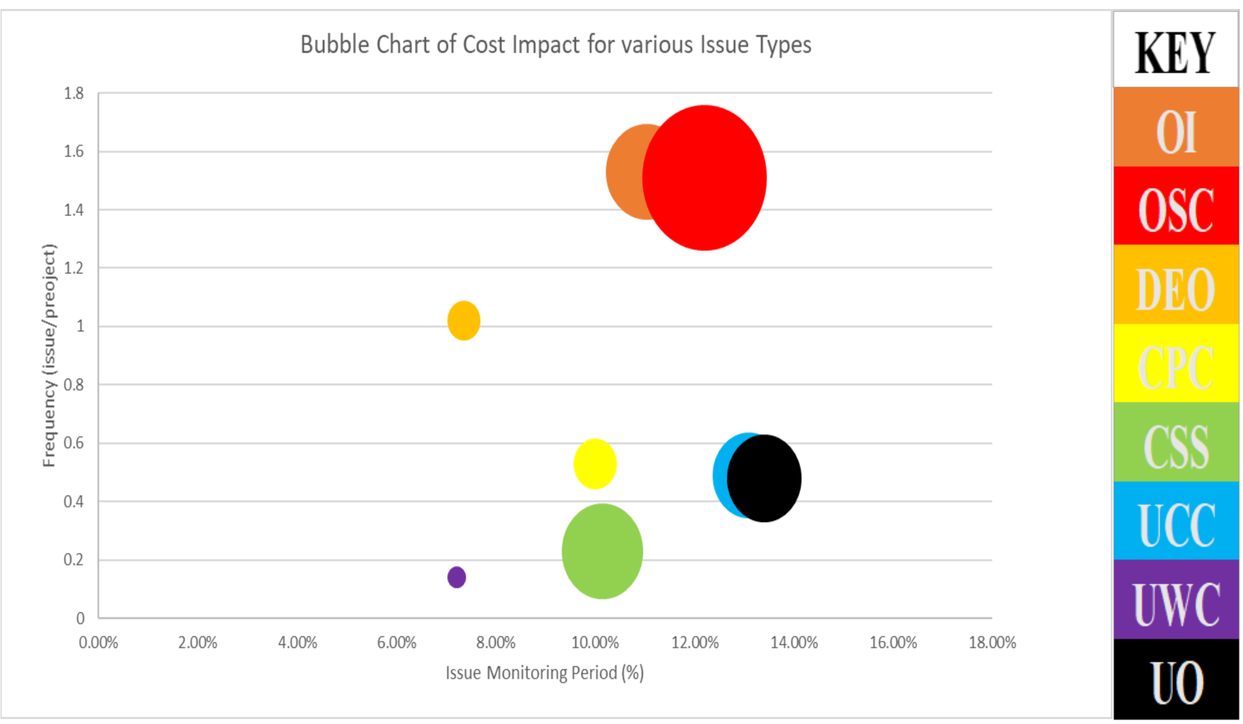

Figure B2. Bubble Chart of Cost Impact by Issue Types and Average Issue Monitoring Period

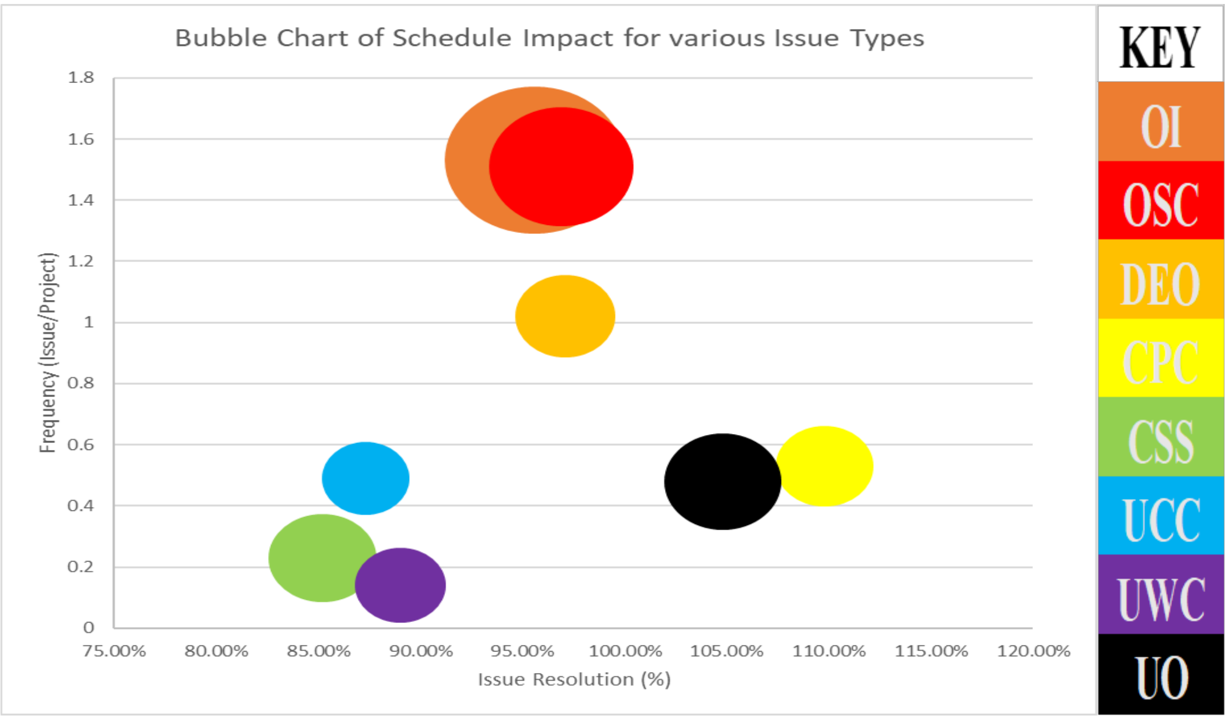

Figure B3. Bubble Chart of Schedule Impact by Issue Types and Average Issue Resolution

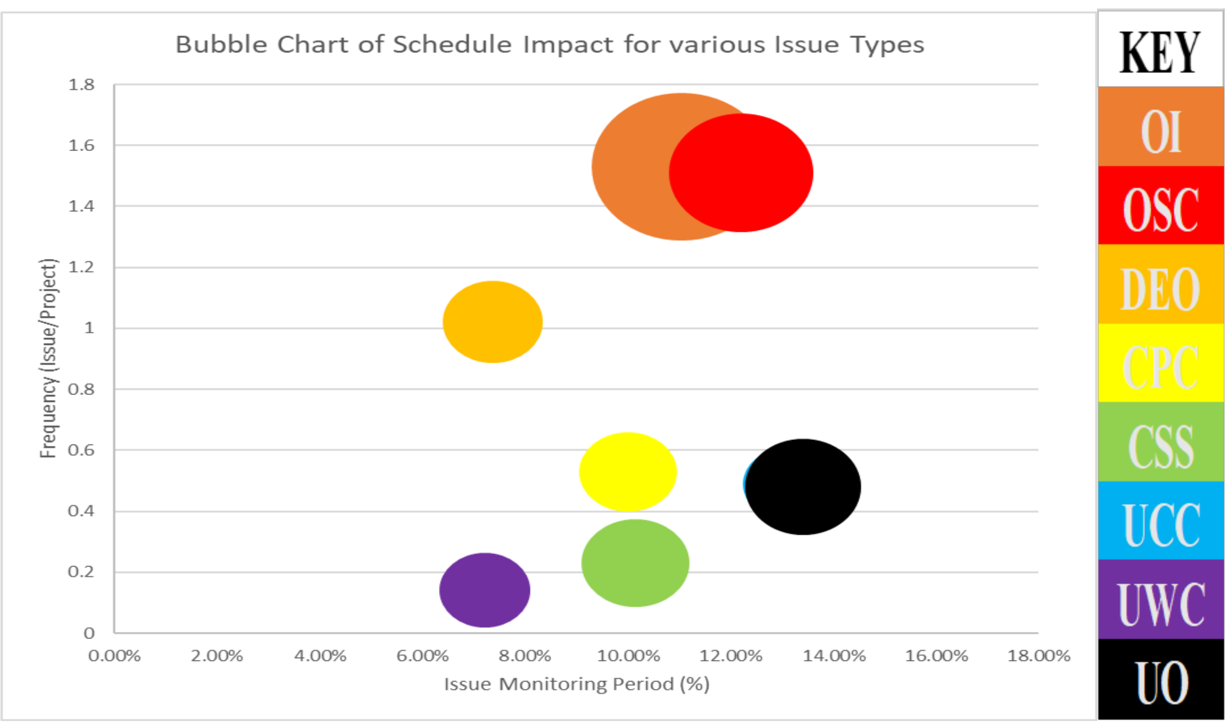

Figure B4. Bubble Chart of Schedule Impact by Issue Types and Average Issue Monitoring Period

APPENDIX C – SUPPLEMENTAL INFORMATION FOR CHAPTER 4

LIST OF TABLES

Table C1. Sub-Hypothesis Statements for the Main Hypothesis for Chapter 4

Chapter	Hypothesis	Statement
4	H8a	Project teams that practice higher issue management implementation tend to achieve lower cost growth.
	H8b	Project teams that practice higher issue management implementation tend to achieve lower schedule growth.
	H9a	Project teams tend to use a consistent level of IMI in the 1st quartile of the project schedule duration for projects with a cost growth
	H9b	Project teams tend to use a consistent level of IMI in the 2nd quartile of the project schedule duration for projects with a cost growth
	H9c	Project teams tend to use a consistent level of IMI in the 3rd quartile of the project schedule duration for projects with a cost growth
	H9d	Project teams tend to use a consistent level of IMI in the 4th quartile of the project schedule duration for projects with a cost growth
	H9e	Project teams tend to use a consistent level of IMI in the 1st quartile of the project schedule duration for projects with a schedule growth
	H9f	Project teams tend to use a consistent level of IMI in the 2nd quartile of the project schedule duration for projects with a schedule growth
	H9g	Project teams tend to use a consistent level of IMI in the 3rd quartile of the project schedule duration for projects with a schedule growth
	H9h	Project teams tend to use a consistent level of IMI in the 4th quartile of the project schedule duration for projects with a schedule growth

Table C2. Pairwise Comparisons Between Different Project Quartiles and Three Level of IMI for Projects with Cost Impact

Base Category -	Comparison Category (%)	Median	t-Statistic	p-value
		Quartile 1		
0 - 33	33 - 66	0.20 - 0.39	-42.534	0.001*
0 - 33	66 - 100	0.20 - 0.81	-137.535	0.000*
33 - 66	66 - 100	0.39 - 0.81	-95.001	0.000*
		Quartile 2		
0 - 33	33 - 66	0.25 - 0.51	-65.131	0.000*
0 - 33	66 - 100	0.25 - 0.87	-156.350	0.000*
33 - 66	66 - 100	0.51 - 0.87	-91.219	0.000*
		Quartile 3		
0 - 33	33 - 66	0.21 - 0.58	-87.927	0.000*
0 - 33	66 - 100	0.21 - 0.88	-161.603	0.000*
33 - 66	66 - 100	0.58 - 0.88	-73.676	0.000*
		Quartile 4		
0 - 33	33 - 66	0.18 - 0.59	-24.840	0.040*
0 - 33	66 - 100	0.18 - 0.81	-104.016	0.000*
33 - 66	66 - 100	0.59 - 0.81	-79.176	0.000*

*p<0.05

Table C3. Pairwise Comparisons Between Different Project Quartiles and Three Level of IMI for Projects with Schedule Impact

Base Category - Comparison Category (%)		Median	t-statistic	p-value
		Quartile 1		
0 - 33	33 - 66	0.12 - 0.34	-4.347	0.000*
0 - 33	66 - 100	0.12 - 0.84	-12.124	0.000*
33 - 66	66 - 100	0.34 - 0.84	-8.003	0.000*
		Quartile 2		
0 - 33	33 - 66	0.15 - 0.40	-4.661	0.000*
0 - 33	66 - 100	0.15 - 0.83	-12.298	0.000*
33 - 66	66 - 100	0.40 - 0.83	-7.994	0.000*
		Quartile 3		
0 - 33	33 - 66	0.18 - 0.52	-5.915	0.000*
0 - 33	66 - 100	0.18 - 0.90	-13.161	0.000*
33 - 66	66 - 100	0.52 - 0.90	-7.493	0.000*
		Quartile 4		
0 - 33	33 - 66	0.39 - 0.64	-4.377	0.000*
0 - 33	66 - 100	0.39 - 0.94	-11.384	0.000*
33 - 66	66 - 100	0.64 - 0.94	-6.843	0.000*

*$p<0.05$