Instantaneous Project Controls:

Current Status, State of the Art, Benefits, and Strategies

by

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ABSTRACT

Despite advancements in construction and construction-related technology, capital project performance deviations, typically overruns, remain endemic within the capital projects industry. Currently, management is generally unaware of the current status of their projects, and thus monitoring and control of projects are not achieved effectively. In an ever-increasing competitive industry landscape, the need to deliver projects within technical, budgetary, and schedule requirements becomes imperative to sustain a healthy return on investment for the project stakeholders. The fact that information lags within the capital projects industry has motivated this research to find practices and solutions that facilitate Instantaneous Project Controls (IPC).

The author hypothesized that there are specific practices that, if properly implemented, can lead to instantaneous controls of capital projects. It is also hypothesized that instantaneous project controls pose benefits to project performance. This research aims to find practices and identify benefits and barriers to achieving a real-time mode of control. To achieve these objectives, several lines of inquiry had to be pursued. A panel of 13 industry professionals and three academics collaborated on this research project. Two surveys were completed to map the current state of project control practices and to identify state-of-the-art or ideal processes. Ten case studies were conducted within and outside of the capital projects industry to identify practices for achieving real-time project controls. Also, statistical analyses were completed on retrospective data for completed capital projects in order to quantify the benefits of IPC. In conclusion, this research presents a framework for implementing IPC across the capital projects industry. The ultimate output from this research is procedures and recommendations that improve project controls processes.

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CHAPTER 1: INTRODUCTION

The monitoring and controlling management process is used to status the work during project execution and is an integral function within owner and contractor organizations' management processes. A reliable and timely reporting of project information is necessary to ensure informed and effective decisions are made on individual projects, the portfolio of projects, and the organization. Most of the time, performance of project metrics such as cost and time are contractually enforced, failing to meet such contractual requirements may result in negative consequences for all involved stakeholders.

Even though frequently overlooked for a successful delivery of a project, project controls is a key function in capital project management. There is no unified definition as to what project controls is (Michalak, 1992), but usually planning, measuring, monitoring, analyzing, decision-making, and corrective actions are all part of project controls (Rozenes, Vitner, & Spraggett, 2006). Various organizations and people have adopted different definitions and elements for project controls. For instance, the Department of Defense (2006) suggests that key attributes of effective project controls are not only the integration of cost, schedule, and progress, but also visible and apparent management, support timeliness of analysis, focus on significant variances and developing trends, forecasts based on past performance, multi-functional team approach to analysis of results, and management focus on developing credible corrective actions. Although cost and schedule metrics have been historically the main focus of project controls, the Project Management Institute (PMI) (2008) lists several management functions as part of the monitoring and controlling process group, which includes project time management, project cost management, project quality management, project communication management, project risk management, project procurement management, and project scope management. Furthermore, Hazir (2015) states that an effective monitoring and controls system should clearly define the following policies: "monitoring policy—what, how, when, and by whom to monitor" and also "intervention and control policy—what, how, where, when, and by whom to prevent, intervene, and correct."

For the purpose of this research effort, Project Controls (PC) is defined as "a practice that encompasses the resources, procedures and tools for the planning, monitoring and controlling of all phases of a capital project's lifecycle, and includes the functions or practices of estimating, risk management, cost and schedule management, change management, earned value progressing and forecasting" (Grau & Back, 2015a). Complementarily, an Instantaneous Project Controls (IPC) function is defined as "a function with continuous data collection and on-demand, accurate reporting" (Grau & Back, 2015a).

In reality, there is a lack of comprehensive understanding of project controls, whether information is instantaneously reported or not. The fundamental functions of project controls beyond the study of estimating and scheduling techniques and data collection technologies has not yet been investigated, i.e., with a holistic and multi-faceted perspective. The reality is that much of the previous research has focused on isolated analysis techniques and even more specifically data collection technologies alone, but little effort has been focused on reporting, decision-making, and corrective action stages of the controls process. For instance, much research has been conducted on automated data acquisition techniques without consideration of how the collected data will be analyzed into meaningful information or reported to the appropriate authority for decision-making purposes, i.e., Ibrahim, Boles, & Fry (2009) and Taneja et al. (2010). Another example is that most forecasting studies (e.g., Back, Boles, & Fry, 2000; Barraza, Back, & Mata, 2004; Kim & Reinschmidt, 2009, 2010, 2011) assume the availability of timely, accurate, and reliable information for analysis purposes without the consideration of the data collection phase. Monitoring and control processes encompass several stages, including planning and creating a baseline for control, gathering of project data to establish current project status, analysis of the raw data into meaningful information, reporting to the decision-making authority, decision making, and finally the act of corrective actions (Figure 1). There are many factors influencing project controls that need to be considered when talking about the subject. These may include project team culture and composition, quality and timeliness of information, and the type of construction contracts utilized. Figure 1 illustrates the control process and project controls influencing factors.

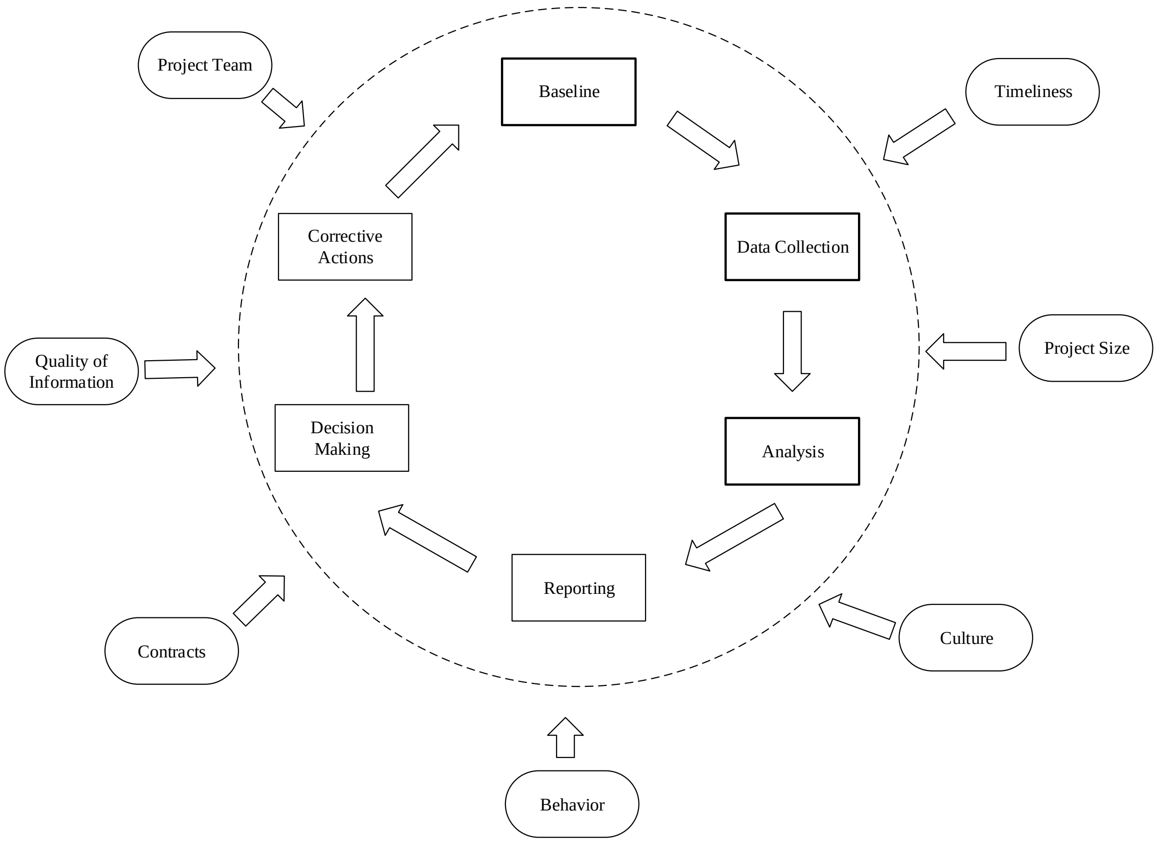


Figure 1: Project Controls Cycle and Influencing Factors

This lack of a comprehensive approach to project controls research becomes evident when realizing that slow and inadequate decision-making (due to missing or delayed information) is a problem in the control process, which has been identified and reported by several scholars (Assaf & Al-Hejji, 2006; Faridi & El-Sayegh, 2006; Odeh & Battaineh, 2002). Many times, decisions are made when it is too late and when the issue at hand has caused adverse impacts to the project. Odeh and Battaineh (2002) indicated slow decision-making and planning weakness as part of the top ten causes for project cost overruns in the Jordanian construction industry. Assaf and Al-Hejji (2006) also cite slow decision-making as a major cause for delays in large building construction projects in Saudi Arabia. A survey of the causes of construction delay in the United Arab Emirates capital projects industry revealed slowness of the owners' decision-making process as the top cause of delay (Faridi & El-Sayegh, 2006). Similar findings were reported as causes of time overruns in Hong Kong construction projects (Chan & Kumaraswamy, 1997).

Knowing the status of a project in a timely manner will help management gain greater insight of their projects, make purposeful decisions, and exercise effective corrective or preventative actions. Without clear, correct, complete, consistent, and recent information, management will not have the ability to take informed actions. In order to mitigate negative variability factors on capital projects, it is crucial for the decision-making authority to have accurate, complete, and reliable information available in a timely manner. Monitoring of project progress should be supported with adequate data collection, analysis, and reporting functions in such a way as to provide a clear and up-to-date status of the project.

The delivery of accurate and timely information for project control purposes is essential to effective management of projects. Around 50–80 percent of the problems on construction sites are attributed to missing and delayed information access (Howell & Ballard, 1997). Timely delivery of information plays a crucial role in achieving project objectives (Abudayyeh, Temel, Al-Tabtabai, & Hurley, 2001; Rojas & Songer, 1999) because it allows appropriate decision-making. The more delay in identification of discrepancies in project objectives the more challenging and costly it is to apply corrective actions. It is estimated that 12.4%of resources are depleted due to late delivery of information to the decision authority, defective materials, and rework late in the construction phase (Burati, Farrington, & Ledbetter, 1992).

Despite the continuous evolution in the project management field, it appears evident that the traditional approaches still show a lack of appropriate methodologies for project control (De Falco & Macchiaroli, 1998). Furthermore, continuous monitoring of the project provides insight into the health of the project and identifies areas needing attention (PMI, 2008).

Research has shown that greater control from project management results in better project performance (Henderson & Lee, 1992; Liu, Chen, Jiang, & Klein, 2010). The quality and timeliness of information flow throughout construction projects has been widely recognized as critical to project management success (Abuddayeh, 2001), thus, it is necessary for all stakeholders and decision makers to have the correct, appropriate information in a timely manner. Different levels of management have distinct responsibilities and have to make unique decisions; the information and presentation that each decision maker needs is different. Thus information presented to management should be clear and good at showing any divergence from planned performance (Al-Jibouri, 2003). Project controls should provide reports unique to each level of management (e.g., control account managers, field office, project managers, owners, corporate managers) with timeliness of information and appropriate level of detail, charts, presentation, and information (Kostelyk, 2012).

In an ever-increasing competitive industry landscape, companies need to be more efficient. As Grau and Back (2015b) point out predictability (timely forecast) of final project cost and time outcome is an important measure of project success. Unfortunately, forecasts of actual project outcomes are unreliable, and actual information is divulged late in the project, which undermines the profitability of the organization (Mulva & Dai, 2012). The research found that project teams lack the ability to make accurate forecasts of at-completion cost and time, which results in inability or reluctance to take corrective actions until additional metrics and indicators are available. Such late availability of information hinders proactive adoption of corrective actions and controls on projects. Currently, project success is assessed based on the deviation of the initial project outcome estimate with the actual outcome at completion. In this kind of outcome-centric performance assessment, when the positive deviations (i.e., overruns) occur, this creates mistrust, concern, and scrutiny. Alternatively, in the case of negative deviations (i.e., underruns), this results in attitudes of trust and satisfaction and, thus, loose mechanism of control (Back & Grau, 2013a). Currently, such project assessments do not encourage the early disclosure of project cost and schedule information, thus the ability to make reliable, timely, and well-informed decisions to effectively support projects is undermined. Such issues warrant a need for more research in the field of project controls.

1.1 Lack of Adequate Reporting Capabilities

Despite advancements in technology, methods and means, and project management procedures, endemic project performance deviations such as cost and schedule overruns still remain pervasive in the capital projects industry (Assaf & Al-Hejji, 2006; Back & Grau, 2013a, 2013b; Flyvbjerg, Holm, & Buhl, 2002; Mott MacDonald, 2002; Mulva & Dai, 2012; Odeh & Battaineh, 2002). Scheduling methods such as Critical Path Method, Program Evaluation and Review Technique, Earned Value

Management, Location Based Planning, Last Planner System and others have been around as early as five decades ago; many variations and extensions to these methods have been proposed ever since. These methods all strive to accomplish a better managed project, a project that meets its performance metrics and objectives. Unfortunately, academia and industry report of an endemic issue in projects meeting their performance targets. One reason for this can be that the development of these scheduling, costing, planning, or project management methods in general have focused specifically on silos of research and have failed to consider project planning, monitoring, and controls as a comprehensive process that encompasses several unique factors and steps. For instance, in many forecasting, scheduling, or cost estimating methods it is assumed that the data being acted upon or analyzed is complete and correct without the consideration of where and how the data is being collected. Another example of how these silos of research fail to construct a comprehensive management method is that they fail to identify how the results of forecasts and estimates are going to be reported to decision authority, who those decision authority are, and how they will take effective corrective actions when the need arises.

Despite the development of the aforementioned scheduling, cost estimating, and planning techniques, these methods fail to take into account a comprehensive view of the process, such as where the data for the analysis is coming from and/or how the results of these procedures or tools should be transmitted to the appropriate authority. In other words, there is no reporting policy, needed frequency, identification of authority, or work breakdown structure that is specified in these plans and procedures.

1.2 Information and Sensing Technologies

Right now, advanced information and sensing technologies may, for the first time in history, enable the improvement of project control processes beyond analysis techniques alone, such as data collection and reporting. Currently, there is unprecedented innovation and availability of commercial technologies to support the improvement of controls. These technologies have shown to improve project performance outcomes (O'Connor & Yang, 2004; Thomas, Macken, & Lee, 2001). Technologies that were not available only decades ago, such as the internet, cloud technologies, and numerous sensing technologies like RFIDs, GPS, and Lidar, pose potential for improvement in the field of project controls and can be used to provide timely data collection and reporting of project information.

In the following sections, these technology improvements will be outlined for data collection, information integration, advanced analytics, and reporting.

1.2.1 Data Collection

Unfortunately, manual collection of data is a common practice in the capital projects industry (Cheun, Suen, & Chueng, 2004; Davidson & Skibniewski, 1995; Saidi, Lyte, & Stone, 2003). The manual data collection process is labor-intensive, time-consuming, and expensive and, as a result, it is performed infrequently (Golparvar-Fard, Peña-Mora, & Savarese, 2009).

Many data capture technologies have been developed in the last three decades. By beginning of 1990s as one of the earliest Automated Data Collection (ADC) technologies (Goodrum et al., 2006), barcodes had been introduced on construction sites as material tracking tools and have since been successfully used in the industry (Navon &

Goldschmidt, 2003). Following successful implementation in other industries, by the mid-1990s, Radio Frequency Identification (RFID) systems were introduced to the construction industry (Ghanem & AbdelRazig, 2006; Jaselskis, Anderson, Jahren, Rodriguez, & Njos, 1995). The Global Positioning System (GPS) is a widely studied tool for the automaton of construction data collection. Laser scanners are able to capture high-resolution 3D data in a short amount of time and due to this capability they have found applications in the construction industry (Kiziltas, Akinci, Ergen, & Tang, 2008). Specifically, laser scanners have found application in quality control (Akinci et al., 2006; Jaselskis, Cackler, Walters, Zhang, & Kaewmoracharoen, 2006), condition assessment (Fuchs, Washer, Chase, & Moore, 2004; Gordon, Lichti, Stewart, & Franke, 2004; Tang, Huber, Akinci, Lipman, & Lytle, 2010), equipment and component tracking (Bosche et al., 2006; Gilsinn, Cheok, Witzgall, Lytle, 2005; Teizer, Kim, Haas, Liapi, & Caldas, 2005), and productivity monitoring (Su, Hashash, & Liu, 2006). A body of research exists on the use of site imagery for continuous and automated data collection purposes. Mobile technology, such as the use of smart phones and tablets for logging project information and reporting, has now become a reality on capital projects.

1.2.2 Information Integration

Key decision-making needs visibility of information and hence information integration (Evgeniou, 2002). Project controls is information intensive; there is a need to retrieve information from different sources, organizations, and software systems. Technology can alleviate the problem of information fragmentation especially when reporting in real-time. Integration of information systems is a crucial component of instantaneous project controls. Integrated and real-time project control systems could have a significantly positive impact in the construction industry (Ghanem & AbdelRazig, 2006; Johnson & Clayton, 1998; Navon, 2005; Navon & Goldschmidt, 2003; Navon & Sacks, 2007). A difficult aspect in implementing the plan for a complex project is the coordination and integration of the various project elements in a way that the project meets its cost, schedule, and performance requirements (Meredith & Mantel, 2003). Integration and automation in construction have been developed and influenced by manufacturing processes (Koskela, 1992). Lack of integration of project monitoring and controls across stakeholders has resulted in isolated decision-making and has caused adversarial relations (Sacks & Harel, 2006).

Non-integrated systems require manual or semi-manual tasks in order to combine project data. Separate information systems require the handling of repetitive data several times, which results in redundant processes. The National Institute of Standards and Technology (NIST) performed a study in 2004 that placed the cost for lack of data integration to the architecture, engineering, and construction (AEC) industry at $15.8 billion (Gallaher, 2004) of which $490 million is due to manually re-entering information in the design and construction phase (Lipman, 2009).

Advancement in computing, such as the development of high capacity and complex data bases inclusive of those with XML syntax and Building Information Modeling (BIM), can enable the storage, update, and retrieval of the immense capital projects data throughout its lifecycle.

1.2.3 Automated Analytics and Reporting

Currently, there is an exceptional amount of data being created by organizations involved on capital projects; the use of technologies can alleviate the management and analysis of these data especially if we want to report in real-time. There is an unprecedented availability of commercial technology products, and technology has evolved tremendously. In the past, to send a man to the moon required a room full of computers; now, a smart phone has more computing power than those early computers. In many industries, analytics and reporting is being done instantaneously and in real-time. For instance, in the financial industry and in stock markets, it is now possible to see market perturbations in real-time on a mobile device. In the manufacturing industry and automobile sector, it is possible to see inventory and sales information in real-time.

Advanced technologies also pose potential benefits to construction data integration and reporting mechanisms. Building information modeling is not only a design tool but also a resourceful tool for consolidating construction project data (Hwang & Liu, 2010; Kang, O'Brien, & O'Connor, 2012). Modern relational databases, such as various forms of XML syntaxes, have found applications in the capital projects domain (Winch, 2002; Zhiliang, Heng, Shen, & Jun, 2004; Zhiliang, Wong, Heng, & Jun et al., 2005). Business intelligence algorithms now enable automatic formatting of reports and reporting to appropriate decision-making authority (Navon & Haskaya, 2006).

1.3 Proposed Departure / Gap of Knowledge

There is a gap of knowledge when it comes to project controls. For instance, the Construction Industry Institute (CII) conducted a research study on project control for design engineering in the 1980s but has not commissioned any other research in the project controls realm until only recently in 2013 (CII, 1987; Grau & Back, 2015a)—a gap of almost 30 years. Research on project controls as a comprehensive process spanning all phases of a capital project is non-existent. The most extensive research to date has only focused on one phase of the project, such as engineering design (CII, 1987; Kostelyk, 2012) or literature reviews that try to summarize the fragmented subjects relating to the topic (Hazir, 2015; Rozenes et al., 2006). The importance of the subject is slowly getting traction in professional societies. For instance CII has recently established a project controls community of practice that is responsible for exchange of project controls knowledge in the capital projects industry (CII, 2016).

In response to these latent shortcomings, this study approaches, for the first time, the project controls process from a holistic perspective, inclusive of data collection, analysis, and reporting functions that are necessary for the project and organizational practices to enable an instantaneous reporting capability. Thus, this novel study addresses several questions that arise, such as:

- What are the adequate reporting frequencies for different project functions and performance metrics?
- For a given control function, does the frequency of reporting vary by project management function?
- How should the reporting frequency of distinct project control functions be prioritized?
- What are the potential benefits of real-time project control technologies on project outcomes?
- What business scenarios can justify the implementation of instantaneous project controls?
- What are the resource requirements (time, cost, labor, etc.) for achieving real-time project controls and timely decision-making?

- What technologies or software tools are being utilized to achieve instantaneous project controls, and what is their commercial availability?
- How is the construction industry currently reporting project performance information?

1.4 Structure of Dissertation

The rest of the discussion in this dissertation is sequentially addressed as follows.

Chapter 1 gives an overview of the research problem and provides motivation and challenges to the topic.

Chapter 2 presents the research hypotheses and objectives.

Chapter 3 provides a comprehensive literature review covering subjects pertaining to project controls.

Chapter 4 elaborates on the research methodology undertaken in this research study.

Chapter 5 describes the surveys regarding current and instantaneous project control practices and illustrates the findings from the survey analysis.

Chapter 6 presents the findings and results of 10 case studies to identify strategies for implementing instantaneous project controls. The interviews protocol, structure, and constructs from the cases study analysis are presented.

Chapter 7 presents statistical analyses of retrospective data from the CII benchmarking and metrics database regarding automation and integration level effect on project performance.

Chapter 8 presents the research intellectual merit and impact.

Finally, **Chapter 9** discusses the findings, conclusions, contribution, and recommendation for future research efforts.

CHAPTER 2: HYPOTHESES AND RESEARCH OBJECTIVES

The research herein strives to overcome the gap in knowledge by investigating project control methods and procedures in a comprehensive manner, which starts from design to commissioning and encompasses functions such as data collection, analytics, and reporting.

The research hypotheses were initially defined and redefined many times during the study to accommodate findings from literature reviews, case studies, and insights gained during the research study. The two hypotheses below represent this final wording, and the research study is constructed around the premise of these two hypotheses.

Hypothesis 1: Specific strategies or practices that, when properly implemented and supported with the right tools and techniques, can result in an instantaneous, or near real-time, project controls function through which current and future cost and schedule status is reported in a precise, reliable, and timely manner.

Hypothesis 2: The impact of instantaneous or near real-time practices expedites project team decision-making, optimizes adjustments in execution strategies, and maximizes the probability for project success and, as such, can be identified and measured.

Specifically, there are three objectives that define this study:

Research Objective 1: the determination of current information and process requirements, by project phase, typically required for supporting project control functions.

Research Objective 2: the development of high-impact strategies to facilitate innovation and to provide instantaneous project control capability. Such strategies should address both the origination ("feed") and accessibility ("read") of project controls information such that real-time, or near real-time, capability is provided.

Research Objective 3: quantify and/or define the benefit and investment costs for instantaneous project control.

The scope of this research is limited to cost, schedule, scope, and quality functions of control and does not include safety functions.

CHAPTER 3: BACKGROUND

No literature on project controls regarded as a comprehensive data collection, analysis, and reporting function to accurately and timely inform on the project condition exists. There is inadequate research and understanding of project controls, irrespective of whether it is instantaneously reported or not, and what appropriate practices are required to support it. The majority of past efforts regarding project controls have been in the realm of estimating and scheduling (e.g., Barraza et al., 2004; Isidore & Back, 2002; Kim & Reinschmidt, 2010, 2011). Additionally, contemporary research has focused on the use of advanced technologies to automatically collect data and generate project-related information. However, these studies have focused on the generation of knowledge around the capability of a specific technology or approach as opposed to providing an understanding of how such technologies and methods can realistically support and inform on the project condition.

Loose monitoring and control of projects may cause adversarial relations and litigation. These adversarial relations are costly; a study indicated that fees paid to lawyers and professionals during the litigation process increased 425% between 1979 to 1990, while an increase of only 309%was seen in settlement and verdicts in the same period (Marcotte, 1990). Thus, litigation costs more to get less in return (Callahan, Bramble, & Lurie, 1990).

The rest of this chapter discusses the importance of project controls in the pretext of endemic cost and schedule deviations, lack of predictability, and lack of timely and informed decision-making support.

3.1 Endemic Cost and Schedule Deviations

Throughout recent years, there have been numerous reports globally on pervasive cost and schedule deviations (oftentimes overruns) on capital projects (e.g., Assaf & Al-Hejji, 2006; Back & Grau, 2013a; Flyvbjerg et al., 2002; Jaseleskis & Ashley, 1991; Mott MacDonald, 2002; Mulva & Dai, 2012). The construction industry maybe more than others has been plagued with various risks that result in cost and time overruns, poor project performance, and even project failures (An, Baker, & Zeng, 2005). These deviations are not limited to one industry sector but have been evident in residential, office, industrial, infrastructure, and other project sectors (e.g., Flyvbjerg et al., 2002). Such deviations show that a more effective mechanism needs to be in place to ascertain appropriate project progress according to plans and objectives. The lack of satisfactory project performance itself indicates a need for better monitoring and control.

The importance of project controls becomes evident after examining construction project deviations (Rozenes et al., 2006). There is a plethora of reports on project overruns. Flyvbjerg et al. (2002) investigated 258 transportation infrastructure projects from 20 different countries and across a 70-year time span. The study reported an average cost escalation of 44.7% for rail, 33.8% for bridge and tunnel, and 20.4% for highway projects. Flyvbjerg, Skamris, Holm, & Buhl (2005) also found that 90% of infrastructure projects experience cost overrun. Assaf and Al-Hejji (2006) conducted a survey in Saudi Arabia among contractors, consultants, and owners and concluded that only 30% of projects were completed within the scheduled completion dates, and also 56% of consultants and 76% of contractors stated that the average cost overrun on projects is 30%. In 2002, the UK treasury reviewed large public projects (inclusive of offices, hospitals, prisons, highways, roads, rails, airport terminals, and information and communication technology facilities) procured in a 20-year span (Mott MacDonald, 2002). Average overruns of 17% on time, 47% on capital expenditures, and 41% on operating expenditures were reported. Recently, Mulva and Dai (2012) indicated that, based on the statistical analysis of 975 owner-completed projects, 70% of the projects experienced a ±10% or larger deviation from planned cost and time. In another recent study, Back and Grau (2013a) reported a 10% median schedule deviation and a 14% median cost deviation at completion for 135 recently completed projects. These perturbations are a major source of uncertainty and risk for the organizations in charge of delivering a project. Jaselskis and Ashley (1991) studied 75 projects mostly in the US and with a majority of projects being process-plant related, manufacturing, office, and infrastructure projects. The investigators found that approximately 58% of projects perform worse than planned in at least one or both cost and schedule. Two thirds of the projects surveyed were from contractor companies while one third was from owner companies. The historic inability to reduce cost and schedule deviations denotes an endemic problem that the industry has yet been unable to tackle and resolve.

3.2 Lack of Predictability

Forecasting is a major and important project controls function. Project managers go beyond finding the status of the project, and look at the possible future outcomes of the project. Such forecasting efforts are made to support timely and effective decision making.

As indicated by recent research (Grau & Back, 2015b), currently projects are not predictable as to what their performance outcome will be in terms of cost and time.

These deviations, whether positive or negative, are frequently “not only by a few percent but by several factors” (Flyvbjerg, 2006). These deviations highlight the importance of early and accurate predictions. The lack of project predictability has many negative implications such that organizations can’t proactively optimize resources (i.e., money) across projects to maximize profitability (Mulva & Dai, 2012). Contrary to intuition, Mulva and Dai (2012) quantitatively showed how both cost underruns and overruns contribute to profitability losses. Their study was based on a statistical analysis of historical data from a 16-year time span. The effects of net present value (NPV) on actual cash-flow balances was investigated for an average project and also for two scenarios. For instance, if project stakeholders know earlier that a project cost will be under what was originally estimated they can reallocate the extra funds to other profitable endeavors. Otherwise, their capital will be allocated to the current project, and potential profitability losses will ensue due to the unused spare budget. On the other hand, early disclosure of project cost overruns doesn’t warranty that these overruns will be reduced or eliminated; however, the disclosure of such overruns ensures increase in monitoring, controls, and scrutiny of the project to suppress further overruns (Back & Grau, 2013a; Callahan, Stetz, & Brooks, 2007). Closer monitoring of project status is needed for better insight into the projects and better predictability of resource utilization and final project performance.

Currently, projects performance is assessed based on a single point deviation between actual outcome and the estimated or baseline outcome. For instance, cost deviations are assessed based on the deviation between baseline cost and total installed cost, while time performance is assessed based on the deviation between baseline schedule and total installed time. This type of outcome-centric performance assessment results in negative assessment when overruns are reported at completion and positive reactions when underruns are reported at completion. Due to this behavior, outcome-centric assessment of project performance harms transparency and hinders the early disclosure of final project outcome; this will negatively affect project controls as there is less information available late into the project lifecycle. Currently, project team members are awarded or punished based on final project performance against the baseline plan. This type of incentives does not award or punish project stakeholders based on early revelation of critical project information. This trend and lack of timely information delivery prevents well-informed decisions and effective control of projects.

3.3 Lack of Timely and Informed Decision-Making Support

One reason for ineffective monitoring and control mechanisms is the unavailability of real-time or at least timely information for decision-making support. Many times project managers have to make critical decisions while in the dark as to the true status of their projects. Oftentimes, information lags within the reporting cycle and the data received by the decision maker may be several months old. In addition to timeliness of information, the information has to be correct, complete, and comprehensive. There have been several studies that attribute subpar capital project performance with the lack of timely information (Back & Grau, 2013a). First, we will discuss lack of timely information and the effects it has on organizational performance from a business point of view and ultimately look at examples of slow decision-making and capital project performance and how this relates with the reviewed business literature.

Business literature indicates that fast decision-making is associated with better project performance as it allows firms to keep up with change (Baum & Wally, 2003; Bourgeois & Eisenhardt, 1988; Jones, 1993). The interest in correlation of decision-making speed with firm performance initially emerged when Bourgeois and Eisenhardt (1988) identified a positive association between fast strategic decision-making and firm performance in "high-velocity" environments, such as microcomputer manufacturing sector. Management advisors have repeatedly prescribed fast decision-making as a source of competitive advantage (Jones, 1993), such as faster time to market, higher profit margins, or higher client satisfaction.

The data from the research indicated that the information used by fast decision makers was not forecasted information but rather real-time information. In the study real-time information is indicated as "information about a firm's operations or environment for which there is little or no time lag between occurrence and reporting." Following these findings Eisenhardt (1989a) developed the following proposition: "The greater the use of real-time information, the greater the speed of strategic decision process" (p. 549).

Rapid decision-making in the wake of real-time information may be for the following reasons (Eisenhardt, 1989a):

(1) Such real-time information may speed up problem or opportunity identification (Dutton & Jackson, 1988).

(2) A more subtle reason is derived from artificial intelligence (AI) research literature. AI literature indicates that "intuition relies on patterns developed through continual exposure to actual situations (Hayes, 1981; Simon, 1987)"

(Eisenhardt, 1989a). The more information available the easier it will become to make inferences and find patterns and trends.

(3) Real-time information might allow teams, managers, and decision makers to gain more experience in responding to problems as a group. More information allows project stakeholders to get more exposure to different scenarios and issues that may occur, thus accruing experience faster.

Also, fast decision makers develop not fewer but more alternatives. It was found that slower decision makers and teams considered less alternatives and only looked for new alternatives when the previous alternatives were no longer viable options. Formally Eisenhardt (1989a) stipulates this as: "The greater the number of alternatives considered simultaneously, the greater the speed of strategic decision process" (p. 556).

It has been shown specifically in the capital projects industry that slow decision-making has adverse effects on project performance. As consistent with business literature, it has been shown that decision-making speed is correlated with performance (Assaf, Al-Khalil, & Al-Hazmi, 1995; Odeh & Battaineh, 2002; Odeyina & Yusif, 1997). A survey of 82 respondents from large public and private buildings, roads, and water and sewer projects in Jordan, with both contractors and consultants surveyed inquired about the most critical reasons for construction delays in their respective projects (Odeh & Battaineh, 2002). Both owners and contractors indicated owner's slow decision-making as one of the 10 top most critical factors causing construction delay in the Jordanian capital projects industry. An older study by Assaf et al. (1995) set out to identify main causes of delay in Saudi large building construction projects. A survey of 24 contractors, 15 architectural/engineering firms, and nine owners was conducted. A major source of delays was identified as owner slow decision-making. Similarly, Odeyinka and Yusif (1997) analyzed causes of delay in the Nigerian building sector and stated slow decision-making as a major source of delay.

3.4 State of Knowledge

Previous project control efforts have focused on scheduling and estimating techniques. Project scheduling began as a research track within the mathematical field of Operations Research with the objective of determining start and finish times of project activities subject to resource and precedence constraints while simultaneously optimizing for certain project objectives (such as cash flow optimization, minimizing project schedule, etc.) (Vanhoucke, 2012). Initial research was done in the late 1950s and mainly focused on network based techniques of Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) scheduling (Vanhoucke, 2012). Despite their age, CPM/PERT techniques are still widely used and are considered important components of the scheduling function for organizations (Ahuja & Thiruvengadam, 2004; Barraza et al., 2004; Vanhoucke, 2012). However, these tools have some limitations, which is why project scheduling research continues to grow in a variety of directions, theoretical models, and applications, such as linear scheduling techniques, simulation techniques, genetic algorithms, time scheduling, resource scheduling, cost scheduling, and more. Scheduling techniques and the determination of final schedules can be grouped using two different approaches: deterministic and probabilistic (Barraza et al., 2004). The deterministic approach estimates final schedule values and outcomes based on point estimates of most likely values, while, probabilistic methods consider variability in duration values when estimating project schedule. As an example of a probabilistic method, Kim and Reinschmidt (2009) use Bayesian inference and the beta distribution to provide confidence bounds on predictions and determine the range of potential outcomes and the probability of success. Furthermore, Kim and Reinschmidt (2010) use Kalman filters and the EVM to make probabilistic forecasts of project duration. In spite of the superiority of probabilistic methods in depicting the variable behavior of projects (Crandall & Woolery, 1982), deterministic methods are more frequently used because they more simple to apply (Barraza et al., 2004). Line-of-balance (LOB) scheduling technique is one of several distinctly important scheduling techniques. LOB scheduling is well suited to linear and repetitive projects, as it is a visual technique where inefficiencies, production rates, and clashes can be found quickly from charts and diagrams.

The Earned Value Method (EVM) is a cost estimating and scheduling technique that is widely used for periodic monitoring of actual expenditures and physical scope accomplishment and, accordingly, for generating period-by-period progress reports (El-Omari & Moselhi, 2011). The Project Management Institute (PMI, 2005) claims that when correctly applied, EVM provides an early warning of performance anomalies. EVM originally coined "Cost/Schedule Control Systems Criteria (C/SCSC)," was developed by the Department of Defense in the 1960s to monitor and control large flexible-priced defense projects (DoD, 1967; Christensen, 1998; Kim, Wells, & Duffey, 2003; Moselhi, Li, & Alkass, 2004; Rozenes et al., 2006). Its appeal is owed to its simplicity, integration of time and cost performance measures, and ability to provide early warning signs on cost performance (overrun or underrun) and schedule performance (ahead or behind) (Vanhoucke, 2009). EVM indicators have been found to be reliable as early as 15% into a project (Fleming & Koppelman, 2000). Better planning and allocation of resources early in the project may be part of this reliability. Succinctly, EVM is based on the representation of three measures: first, the budgeted cost for work scheduled (BCWS)—also called planned value (PV); second, the actual cost for work performed (ACWP)—also called actual cost (AC); and finally, the budgeted cost for work performed (BCWP) or earned value (EV). EVM integrates cost, schedule, scope, and technical performance under the same framework, and it provides metrics that allow managers to detect cost or schedule deviations (Fleming & Koppleman, 2000; Kerzner, 2003; Kim et al., 2003; Naeni, Shadrokh, & Salehipour, 2011; Plaza & Turetken, 2009; Warhoe, 2004).

The Last Planner System™ (LPS) is an implementation mechanism of Lean Construction (Ballard, 1997, 2000). It aims at enhancing the reliability of the weekly work plan. According to Ballard, LPS is a production planning approach that integrates pull planning, look-ahead planning with constraint analysis, weekly work planning based upon reliable promises, and learning based upon analysis of Plan Percent Complete (PPC) and reasons for variance to improve workflow (Ballard, Kim, Jang, & Liu, 2007). In the LPS, the last planner is the ultimate individual responsible for planning the actual execution of the work. This approach introduces a transfer of accountability from management to the workforce.

3.4.1 Limited Approach to Controls

More information is needed by managers to make decisions (Chau, Cao, Anson, & Zhang, 2003); project information is derived from different sources that need to be integrated (Ahmad, Azhar, & Lukauskis, 2004). Current research has focused on silo thinking and segregated techniques and has not considered the overall process. Data collection efforts do not consider analysis or reporting and only focus on obtaining the data. In spate efforts, analytics only focuses on methods and techniques with disregard for where and how the data that is fed into its algorithms is collected. In many academic papers, complex analytic techniques are explained, but they oftentimes do not explain how they will be implemented in the project management system of an organization. Examples include where the data is coming from, who it is to be reported to, and with what frequency. As an example of analytics, Kim and Reinschmidt (2009, 2010, 2011) propose several elaborate in-depth various probabilistic forecasting methods. Kim and Reinschmidt (2009, 2010) use Bayesian inference, the beta distribution, and Kalman Filters, to more accurately forecast project cost and time at completion as compared with classical CPM/PERT methods. Although these propositions have strong intellectual merit, they lack much practicality.

There have been instances where the process of data collection, analysis, and reporting has been streamlined for a specific function. For instance, Navon and Shpatnitsky (2005) propose a model that automatically collects earthwork information and processes the monitored data into useful information to the construction manager in real-time. Their model was used for road construction. It uses GPS technology to automatically collect earthmoving equipment locations and uses proprietary algorithms to convert these location data to control information, such as productivity, duration (or progress), and actual consumption of materials. Specifically, El-Omari and Moselhi (2011) investigated the practicality of several automated data acquisition technologies, which includes bar coding, RFID, 3D laser scanning, photogrammetry, multimedia, and pen-based computers. Their cost/schedule model integrates these automated data acquisition technologies with relational databases, planning and scheduling softwares, and AutoCAD to produce progress reports that can be used in the decision-making process by project management.

3.4.2 Availability of Sensing and Information Technologies for Instantaneous Controls

Project controls is a function that has traditionally required manual collection, aggregation, and analysis of a large volume of multiple data sets from distinct sources, e.g., with different formats and supported by different tools. Thus, the inability to automatically collect and process large volumes of defragmented data has been preventing the consideration of an instantaneous controls capability. But now, with the availability of new technologies, it is possible to instantaneously report project information to the appropriate authority. With advancements in field data capture, analytics, and computing, it is now possible to have access to accurate, reliable, and complete data on demand and instantaneously.

Unfortunately, manual collection of data is a common practice in the capital projects industry (Cheung et al., 2004; Davidson & Skibniewski, 1995; Saidi et al., 2003). Manual data collection process is labor-intensive, time-consuming, and expensive; as a result, it is performed infrequently (Golparvar-Fard et al., 2009). Furthermore, manual processes pose data inconsistency, redundancy, and data entry error problems (Abudayyeh & Rasdorf, 1993). Accuracy of the collected data depends on the skill level and judgment of the individual collecting the data (Liu, 1995).

Automated data collection is the use of electronics or computers with minimal human interface for the collection of project data. Automated data collection permits the continuous and instantaneous feed of data for analysis and reporting function purposes, thus contributing to successful execution of projects (Russell, 1993). Traditionally, field data collection has been difficult (Hwang & Liu, 2010). As a solution, the industry has looked for answers within the technology realm (Hwang & Liu, 2010). Various real-time data collection systems have been developed with the aim of automating control of construction projects (Hwang & Liu, 2010). There has been extensive work on automated sensing technology that has helped in bypassing manual collection of data (Taneja et al., 2010). Such modern technologies are becoming more available and less expensive (Navon & Sacks, 2007) and help in the timeliness, accuracy, and integrity of data collection (Rasdorf, 1990). Many automated data acquisition and control techniques have been investigated in the past two decades (Isaac & Navon, 2014). Fortunately with the advancements in field data capture technologies such as smart tags, laser scanners, embedded sensors, GPS devices, RFID scanners and more, it is now possible to collect, store, and reuse accurate, complete, and reliable field data (Kiziltas et al., 2008).

Key decision-making needs visibility of information and, hence, information integration (Evgeniou, 2002). In many industries, including the capital projects industry, the problem is that information is spread across organizations and stakeholders, disparate information systems exist, and information is presented in different modes and standards across the enterprise (Evgeniou, 2002). A difficult aspect in implementing the plan for a complex project is the coordination and integration of the various project elements, in a way that the project meets its cost, schedule, and performance requirements (Meredith &

Mantel, 2003). For instance, in construction projects there is typically one general contractor and many subcontractors that may work in different information systems and present information in different formats. Lack of integration of project monitoring and controls across stakeholders has resulted in isolated decision-making and has caused adversarial relations (Sacks & Harel, 2006). In order for the project manager to make effective decisions, this information should be integrated and visible to the manager.

Integrated and real-time project control systems could have a significantly positive impact in the construction industry (Ghanem & AbdelRazig, 2006; Johnson & Clayton, 1998; Navon, 2005; Navon & Goldschmidt, 2003; Navon & Sacks, 2007). Integration and automation in construction have been developed and influenced by manufacturing processes (Koskela, 1992). The advent of the internet opened up myriad possibilities for all industries, including construction projects; the potential implications of the web positively increased as it has matured (i.e., cloud computing). During the late ’90s and early 2000s, the internet came to be recognized as a tool for the integration of historical and current project data and the remote entry of data into data management systems (Abudayyeh et al., 2001; Rojas & Songer, 1999). Web-enabling technologies have been used as a tool for the integration of information systems (Cheung et al., 2004; Moselhi et al., 2004; Rojas & Songer, 1999). In 1997, Walker and Betts (1997) forecasted that the internet and the World Wide Web would revolutionize construction business structure. Some researchers (Chan & Leung, 2004; Chou & Chong, 2008; Li, Moselhi, & Alkass, 2006; Moselhi et al., 2004) have applied web-based systems for convenient data collection and data sharing over the internet. BIM can facilitate the integration of real-time field data collection technology into the project management framework (Hwang & Liu, 2010). For example, a system developed by Golparvar-Fard et al. (2009) can assist with automatic update of building information models while its primary purpose is to monitor progress.

3.5 Advanced Technologies and Project Performance

Automated data-collection, analysis, and reporting methods have been devised as a partial solution to the stagnant project controls capability (Rebolj, Babič, Magdič, Podbreznik, & Pšunder, 2008). It has already been documented that the ability to share and analyze information can have a positive impact on project performance. A NIST-sponsored study carried out by Thomas (2000) and Thomas et al. (2001) evaluated the impact of design/information technology (D/IT) adoption on project performance metrics such as cost, schedule, and safety. Specifically, they looked at four technologies: (1) integrated database, (2) electronic data interchange (EDI), (3) three-dimensional (3D), and (4) computer-aided design (CAD) modeling and bar coding. The authors determined that such technologies can improve project cost and schedule performance. Furthermore, Thomas, Lee, Spencer, Tucker, and Chapman (2004) conclude that an increase of D/IT will result in cost savings of approximately four percent.

In another detailed study, O'Connor and Yang (2004) conducted a survey on more than 200 capital facility projects and quantified the benefits of information technology adoption on project cost and schedule performance. Their analyses includes those at the project level and phase level for high-tech and low-tech work functions and specifically their relationship with information integration and automation levels. Their study measures IT use across six project phases (front-end planning, design, procurement, construction management, construction execution, and startup/operations/maintenance);

each phase includes several work functions. O'Connor and Yang's (2004) statistical analysis indicated that technology advancements improve both project cost and schedule at the project level but are more prominent in reducing schedule growth. Also, project schedule success is found to be correlated with the following levels: (1) project level, (2) integration level, (3) front-end phase, and (4) construction execution phase. Additionally, project cost success is correlated with technology usage for industry-wide, high-tech work functions, but the correlation is relatively weak.

The studies noted were conducted more than a decade ago. It could be expected that with the technologies available today the impact of integration and automated analytics could be larger. Too often the Return on Investment (ROI) of information technology is not evaluated pre- or post-implementation due to the perceived difficulty of the evaluation (Johnson & Clayton, 1998). As with most competitive industries, the capital projects industry needs to quantify the costs, benefits, and business implications of information technology usage. For this reason, several scholars have attempted to identify and quantify the benefits from the adoption of these technologies. Through a simulation technique, Back and Bell (1994) showed that internal information integration in industrial capital projects decreased both project cost and time. A study by Johnson and Clayton (1998) suggests that team productivity and management procedures may improve by adopting information technology in AEC firms. Back and Moreau (2000) suggest that information integration within and across organizational boundaries reduces project time and cost. One of the first efforts to quantify the benefits of information technology adoption was by Thomas (2000) who evaluated the impact of information technology adoption on project performance metrics such as cost, schedule, and safety and contended that such technologies can reduce project cost and schedule growth.

The adoption of new technologies in the capital projects industry has been slower than other industries, such as manufacturing. Such a lack of investment may be due to lack of statistical studies to support the utilization of such technologies. Too often the ROI of information technologies is not evaluated due to the perceived difficulty of such evaluation (Johnson & Clayton, 1998). As such, the capital projects industry needs to quantify the costs, benefits, and business implications of real-time project controls with the support of information technologies. For this reason, several scholars have attempted to identify and quantify the benefits from the adoption of these technologies.

There are relatively few research studies that have attempted to show the impact of technology usage on construction project performance. Of the extant studies, an early study by Griffis, Hogan, & Li (1995) studied the effects of 3D CAD models on project cost (actual cost/estimated cost), schedule (actual schedule/estimated schedule), and rework (additional labor expenditure due to rework/total labor expenditure of the project) in industrial projects and found improvement in these three key project parameters. Specifically compared to projects that use traditional design and construction methods, they report a five percent reduction in cost growth, four percent reduction in schedule slip, and 65% reduction in rework. These reported results are based on a survey of 55 CII companies. To validate their survey results, Griffis et al. (1995) conducted a case study of a project that used 3D CAD. The project staff were asked to identify problems that were avoided due to use of these models. Furthermore, based on conservative estimates a cost reduction of 12% was shown validating the survey results.

De Lapp, Ford, Bryant, & Horlen (2004) studied the impact of CAD on design realization. Johnson and Clayton (1998) studied the impact of information technology on facility design and construction from the owner's perspective and suggested that team productivity and management procedures may improve by adopting information technologies.

Back and Bell (1994) attempted to identify the impact of electronic data interchange (EDI) in bulk materials management and showed through a simulation technique that internal information integration in industrial capital projects could improve both project cost and time outcomes. Back, Moreau, & Toon (1996) investigated the effect of information management on project cost and schedule performance. The researchers modeled a single information technology solution using Visual Basic program and concluded that such a single approach may not result in a significant project-level impact. Back and Moreau (2000) investigated the cost and schedule impacts of information management systems on EPC projects in order to quantify the business impact of information management strategies and the associated investment in information technology. They concluded that implementation of information integration strategies for design related and material management activities may reduce the project schedule by 14% and project cost by eight percent.

Using a similar methodology to study IT use, El-Mashaleh, O'Brien, & Kang (2006), through quantitative analysis, found that higher technology usage correlates to better schedule, cost, and some composite metrics. Additionally, they concluded that schedule performance experiences higher improvement by use of technology than does cost performance; also, no positive impact was found on safety. They developed an IT rating index similar to that of O'Connor and Yang (2004). Their analysis specifically showed that one unit of technology improvement will increase schedule performance by five percent and cost performance by three percent. Yang, O'Connor, & Chen (2007) explored the links between technology usage and project outcomes through assessment of technology usage at the work function level for 98 capital facility projects and concluded that information and data-intensive work functions may contribute to better cost, time, and quality performance.

Yang, O'Connor, & Wang (2006) studied the level of technology employed across 68 project work functions across 209 completed projects across the US. The primary objective of their study was to investigate the success-technology relationship across different project sizes and conclude that such a relationship is more prominent for medium and small projects as opposed to large projects.

Kang, O'Brien, Thomas, & Chapman (2008) studied CII benchmarking data and concluded that CII owner companies experience two percent improvement in cost growth and 17% improvement in schedule growth from technology use. Zhai, Goodrum, Haas, & Caldas (2009) showed that construction labor productivity is positively related to the use of automation and integration technologies. Froese (2010) investigated the impact of emerging information technology on project management for construction projects.

Kang et al. (2012) present an analysis of benefits and hindrances for specific information integration implementations in the industrial construction sector.

The studies presented above indicate the importance of technology usage in construction projects and suggest improvements in project and firm performance from the implementation of such technologies.

The research herein contributes to the body of knowledge by providing a practical understanding of the effect of information integration and automated analytics on project cost and schedule performance. The understanding of past technology improvement on project performance allows management as well as developers of new technologies to realize the benefits of such technology utilization and helps them in making prudent decisions by providing economic value of using information technologies.

CHAPTER 4: RESEARCH METHODOLOGY

In this chapter, the research methodology will be outlined. Each research tool used will be described, including the survey tools, statistical analysis, and multiple case study method, in the following paragraphs.

4.1 Overview

The lack of knowledge in the subject area instigated the pursuit of this problem from a practical perspective—problem-centered and pluralistic—using a mixed-method form on inquiry. Thus, several lines of inquiry were sought in this research project to achieve the research objectives (stated in Chapter 2). The research methodology includes hypothesis development, literature reviews, two online surveys, research charrettes, statistical analyses of retrospective capital project databases (quantitative), and an exploratory multiple case study (qualitative). Figure 2 diagrammatically explains the research method.

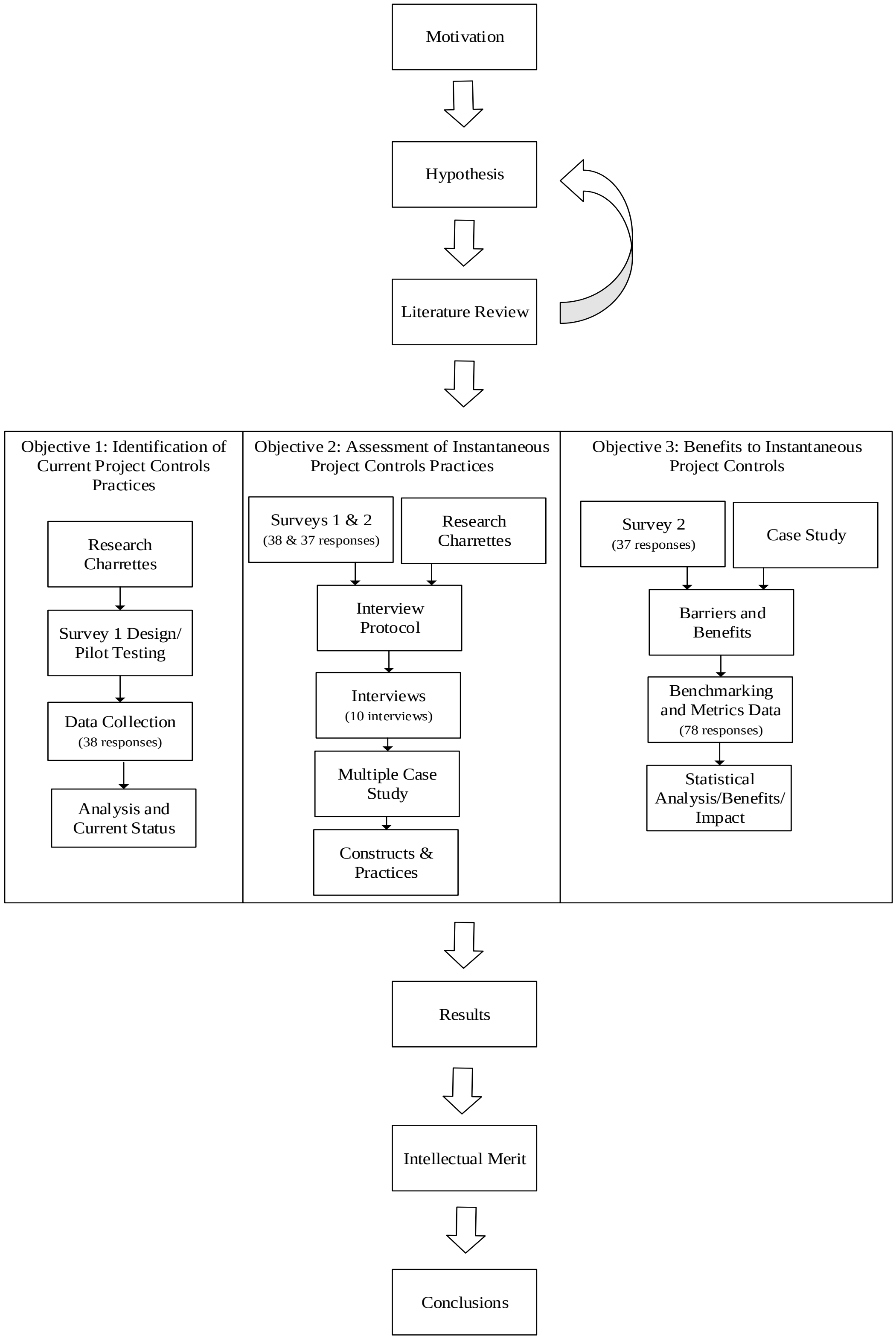


Figure 2. Research Methodology

4.2 Literature Review

First, an extensive literature review of technical journals and industry publications was undertaken. The literature evidences a noticeable lack of research on the subject matter and especially of research pertaining to project controls as a comprehensive method that encompasses many processes; thus, the objective of the literature review was to find key topics, trends, and research statuses pertaining to project control subject areas, such as forecasting, integration methods, data collection, and more. The research hypothesis was redefined and refined several times using the insights gained from the literature review.

4.3 Research Charrettes

Using structured workshops or research charrettes, it is possible to elicit ideas and industry experience in a short amount of time for the purpose of gaining innovative and useful research findings (Gibson & Whittington, 2009). According to Grau and Back (2014), "Research charrettes encompass a dynamic, creative generation and sharing of a large amount of information in a short amount of time" (p. 18). A steering committee of a number of senior project controls specialists from top contractor and owner companies provided their experience and valuable insights into the subject matter (members mentioned in acknowledgements section of this dissertation). During a two-year period, monthly tele and web conference calls were held, and bi-monthly face-to-face meetings were held across North America for two to three days at a time. Before each assembly, a meeting agenda was developed and sent to participants to facilitate the planning and execution of the structured and unstructured exercises. Also, several subcommittees were established that held remote conference calls to coordinate specific project objectives that were later reported to the entire team for further discussion.

4.4 Surveys

Two surveys were developed and distributed among CII member companies. The survey respondents were a diverse set of owner and contractor companies within the public and private sector. Survey 1 investigated the current or batch conditions of project controls within the construction industry, which is in line with objective 1 of the research study. Survey 1 quantified current data collection and reporting frequencies for various control functions across different project phases. A major contribution of the batch conditions survey or Survey 1 was the definition of project control functions for the design, procurement, construction, and commissioning phases of the project, which is something that has not been addressed in literature prior to this effort.

Survey 2 was intended to discover instantaneous project control elements, barriers, benefits, characteristics, and requirements. Survey 2 investigated barriers and benefits to the implementation of instantaneous project controls, which are functions that are being monitored and controlled instantaneously, and also the perceived benefits of IPC on cost, schedule, quality, and scope across project phases. This survey contributed to objectives 2 and 3 of the research study—identification of IPC practices and quantification of benefits of IPC. Surveys 1 and 2, along with research charrettes, were used to construct the interview protocol that later supported the case studies and objective 2. Also, Survey 2 indicated top barriers to implementation of IPC, which subsequently related to CII Benchmarking and Metrics Data, as shown earlier in Figure 2.

4.5 Multiple Case Study Research

To fulfill research objective 2—the development of high impact strategies and practices that facilitate the implementation of IPC—an exploratory case study research methodology was adopted (Eisenhardt, 1989b; Glaser & Strauss, 1967; Yin, 1994). Yin (1994) describes case study research as an "empirical inquiry that investigates contemporary phenomenon within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident".

As part of the preparatory phase of the case studies and prior to the interviews, an interview protocol was designed to collect data from companies within and outside CII membership. During preliminary interviews and discussions (not part of the main case studies), we followed an opportunistic approach (Eisenhardt, 1989b), meaning we identified emerging issues and modified our questions accordingly to better reach our objective. This approach resulted in a standardized open-ended interview protocol used in the subsequent case studies. Companies with at least one instantaneous controls function were identified by research panel members, and, ultimately, 10 companies not only in the construction domain but also in the technology, manufacturing, and aerospace industries were contacted. The interviews were held either by phone or face to face with interviewees within the higher managerial positions and experts affiliated with companies regarded as leaders within their respective industries. The case studies fulfilled the need for an external cross-validation since it enabled the identification of common characteristics, traits, and trends from multiple industry, management, and technical perspectives. The strategic selection of cases and the carefully selected questions produced complementing and replicating evidence, which increased the internal validity of our constructs (De Vaus, 2004; Eisenhardt, 1989b; Yin, 1994). The data collection or case studies were stopped when we reached theoretical saturation (Auerbach & Silverstein, 2003), meaning we stopped interviewing new companies when the insights became repetitive, and at this point, we started analyzing the collected data.

Most interviews were recorded and transcribed in order to perform a careful within-case analysis (Eisenhardt, 1989b) to shortlist relevant information. These case studies were analyzed through triangulation of evidence to develop constructs that were used to identify high-impact practices and strategies that help companies achieve IPC solutions. In total, 88 issues were shortlisted, referred to as "incidents," and grouped into similar themes referred to as "categories" or "codes" (Glaser & Strauss, 1967). Emerging incidents were compared with themes to identify important emerging themes to form key constructs. In this way, nine key constructs emerged.

The strength of this research lies in the inclusion of multiple case studies to examine the same relationships across organizations and project types and to reach a level of generalization. The inclusion of multiple case studies allowed for triangulation in data collection, which subsequently enabled verification of emergent issues from multiple sources to achieve convergence.

4.6 Statistical Analysis

In Survey 2, analysis of the 37 subject matter responses from 18 distinct organizations revealed that information integration was cited as the top barrier and process automation as one of the top barriers to IPC implementation. These two functions were considered as proxies of IPC. Incidentally, CII Benchmarking and Metrics (BM&M) survey version 11.0 had investigated the maturity of internal and external integration as well as process automation within construction organizations. We utilized the useful portion (78 responses) of this retrospective benchmarking database to quantify the benefits of IPC on project performance. We categorized best and worst in class projects based on their integration and automation maturity and statistically compared the schedule and cost performance of these two groups to achieve objective 3 or the objective to determine the impact of IPC on project performance.

CHAPTER 5: CURRENT STATE OF KNOWLEDGE

Survey 1, or the batch mode survey, was designed to satisfy objective 1 of this research project. As previously mentioned, objective 1 of this research project is the determination of *current* information and process requirements, by project phase, typically required for supporting project control functions. In this chapter, the survey design, project characteristics, and results, such as information systems used during the project and frequency of monitoring and controls for specific functions during different phases of the projects, are outlined. Survey 1 or the batch mode survey is presented in Appendix I.

In order to avoid biased findings and conclusions, the data collection included a representation from a broad range of industry organizations and projects, such as both public and private sectors, and a balance between owner and contractor perspectives.

5.1 Survey 1—Batch Mode Survey

In this section, the design, data collection, respondent and project characteristics, descriptive statistics, and findings regarding project information technology utilization and reporting frequency for project management functions are reported.

5.2 Design

The first survey was administered online through an online survey tool named Select Survey; access to this website was provided by CII. The online survey was initially beta tested internally among research team members before sending to the surveyed for final responses. The targeted respondents were project control managers and specialists as well as project managers. The survey was open for three months and was extended several times to allow more responses to be returned.

Current project controls issues addressed in the survey included, but were not limited to, reporting frequencies for project control functions per phase to both project manager and client or ultimate authority or the characterization of computing tools and systems to satisfy controls and management processes. Also, a fundamental aspect of the survey design was the accurate definition of the different project control functions required during the design, procurement, construction, and commissioning and startup phases. The project control functions were defined by a subcommittee of subject matter experts involved in the research project (Grau & Back, 2016). The meetings were administered online by the author in four separate hour-long sessions. Table 1 to Table 4 illustrate the concluding project control functions for the engineering, procurement, construction, and commissioning and startup phases.

Table 1

Project Control Functions—Engineering Design Phase

Cost	Schedule	Scope
1. Plan Baseline/Control Budget	1. Develop Baseline Schedule	1. Develop Control Scope (baseline scope plus approved change orders)
2. Monitor Committed Cost (actual obligated/contracted cost to perform work)	2. Monitor Major Milestone Progress/Engineering Performance Against Baseline Schedule	2. Monitor Change Order Status
3. Monitor/Control Change Order Cost	3. Estimated Time to Completion	3. Monitor Change Order Impact to Project Schedule and Cost
4. Monitor Budget (baseline plus approved change order)		
5. Monitor Actual Expenditures (actual engineering cost to date)		
6. Plan/Control Estimate to Complete for Current Engineering Phase		
7. Monitor Engineering Performance (earned value progressing)—Performed vs Planned		
8. Plan/Monitor Risk Analysis (should include all risks & outstanding changes)		
9. Estimate the Total Engineering Cost for all engineering phases		
10. Monitor Accounts Payable		
11. Monitor Accounts Receivable		
12. Monitor/Control estimated Total Installed Cost		

Table 2

Project Control Functions—Procurement Phase

Cost	Schedule	Scope	Quality
1. Plan Baseline/Control Budget	1. Develop Baseline Schedule	1. Develop Control Scope (baseline scope plus approved change orders)	1. Quality Tests and Inspections
2. Monitor Committed Cost (actual obligated/contracted cost to perform work)	2. Monitor Major Milestone Progress / Procurement Performance against Baseline Schedule	2. Monitor Bid Tracking Log (item, bidders, request for proposal, responses received, bid tab, etc.)	2. Quality & Turnaround of Requests for Information (RFIs)
3. Monitor/Control Change Order Cost	3. Estimated Time to Completion	3. Monitor PO Tracking Log (item, PO #, vendor)	
4. Monitor Budget (baseline plus approved change order)		4. Monitor Change Order Status	
5. Monitor Actual Expenditures (actual engineering cost to date) Plan/Control Estimate to Complete for all phases		5. Monitor CO impact to project schedule and cost	
6. Monitor Procurement Performance (earned value progressing)— Performed vs Planned			
7. Plan/Monitor Risk Analysis (should include all risks & outstanding changes)			
8. Monitor Accounts Payable			
9. Monitor Accounts Receivable			
10. Monitor/Control estimated Total Installed Cost			

Table 3

Project Control Functions—Construction Phase

Cost	Schedule	Scope	Quality
1. Plan Baseline/Control Budget	1. Develop Baseline Schedule	1. Develop Control Scope (baseline scope plus approved change orders)	1. Quality Tests and Inspections
2. Monitor committed Cost (actual obligated/contracted cost to perform work)	2. Monitor Major Milestone Progress / Procurement performance against Baseline Schedule	2. Monitor Change Order Status	2. Quality and Turnaround of Requests for Information (RFIs)
3. Monitor/Control Change Order Cost	3. Estimated Time to Completion	3. Monitor CO Impact to Project Schedule and Cost	3. Rework Hours / Costs
4. Monitor Budget (baseline plus approved change order)			
5. Monitor Actual Cost/Expenditures to Date (including OT)			
6. Estimate Total Installed Cost			
7. Monitor Construction Performance Measurement—Performed vs Planned (hours & quantities)			
8. Monitor Risk Analysis (should include contingency reconciliation)			
9. Monitor Accounts Payable			
10. Monitor Accounts Receivables			

Table 4

Project Control Functions—Commissioning and Startup Phase

Cost	Schedule	Scope	Quality
1. Plan Baseline/Control Budget	1. Develop Baseline Schedule	1. Develop Control Scope (baseline scope plus approved change orders)	1. Quality Tests and Inspections
2. Monitor committed Cost (actual obligated/contracted cost to perform work)	2. Monitor Major Milestone Progress / Commissioning performance against Baseline Schedule	2. Monitor Change Order Status	
3. Monitor/Control Change Order Cost	3. Estimated Time to Completion	3. Monitor CO impact to project schedule and cost	
4. Monitor Budget (baseline plus approved change order)			
5. Monitor Actual Cost/Expenditures to Date (including OT)			
6. Estimate Total Installed Cost			
7. Monitor Commissioning Performance Measurement —Performed vs Planned (hours & quantities)			
8. Monitor Risk Analysis (should include contingency reconciliation)			
9. Monitor Accounts Payable			
10. Monitor Accounts Receivables			

5.3 Data Collection

A total of 38 individual projects were reported from 11 distinct organizations. Twenty-one of those projects were reported by owner companies, and the rest were reported by contractor organizations. Research team participants, representing a wide variety of industries and organizations, facilitated the completion of the surveys. In all, 38 subject matter experts, with an average of 24 years total experience and 19 years of experience specifically in project controls, each responded to the survey. Out of the 38 reported projects, six projects are still finalizing at completion budget. The total installed costs for the completed projects (32 projects) were more than $31.7 billion. For those 32 projects, average cost overrun were 15.43%. Out of the 38 projects, two projects were in the process of finalizing expected projected completion schedules. For other 36 projects, the average schedule deviation were more than 5.5 months, and average schedule overrun was 15.2%. Most of the projects were in private sector (Table 5), greenfield type (Table 6), heavy industrial in nature (Table 7), not financed by third-party sources (Table 8), delivered using Design-Bid-Build (Traditional) method (Table 9), using Lump Sum contracts (Table 10), located in familiar geographic location (Table 11), located in North America (Table 12), and have both central and local offices for project controls (Table 13).

Table 5

Projects' Distribution by Public and Private Sectors (%) (Question 8)

Private Sector	Public Sector	Both
73.7	15.8	10.5

Table 6

Projects' Distribution by Nature of the Project (%) (Question 16)

Grass Roots, Greenfield	Brownfield (co-locate)	Modernization, Renovation, Upgrade (changes to existing capacity)	Addition, Expansion
33.3	19.3	28.1	19.3

Table 7

Projects' Distribution by General Industrial Sectors (%) (Question 11)

Heavy Industrial	Light Industrial	Buildings	Infrastructure	*Other Sector
73.8	4.8	7.1	11.9	2.4

*Other sector: Science

Table 8

Projects' Distribution by Third-Party Finance Sources (%) (Question 9)

Yes	No	In part or to some extent	Don't Know
15.8	68.4	10.5	5.3

Table 9

Projects' Distribution by Project Delivery Method (%) (Question 26)

Design-Bid-Build (Traditional)	Design-Build (EPC)	Construction Management at Risk	Development	Fast Track	Turnkey	Other Project Delivery Method
40.0	22.9	11.4	8.6	11.4	2.9	2.9

Table 10

Projects' Distribution by Type of Contract Used in Projects (%) (Question 27)

Lump Sum	Time and Materials	Guaranteed Maximum Price (GMP)	Unit Price	Cost Plus Fixed Fee	Other Contract Type
37.5	25.0	7.1	8.9	16.1	5.4

Table 11

Projects' Distribution by New Geographic Location or Region (%) (Question 10)

New Geographic Region	Familiar Geographic Region
23.7	76.3

Table 12

Projects' Distribution by Geographic Region/Location (%) (Question 25)

United States	Canada	Western Europe	Asia	Middle East	Oceania	Africa
64.1	10.3	2.6	15.4	2.6	2.6	2.6

Table 13

Projects' Distribution by Structure of Project Control Offices (%) (Question 35)

Central Project Controls Office	Local Project Controls Office	Both Central and Local Offices
5.4	37.8	56.8

The procured functions in most projects were materials and equipment (Table 14). Additionally, new technology and processes were used in about 36% of the projects (Table 15). The level of familiarity with the new technology or process used during design and execution phases of the project were mostly moderate in nature (Table 16). In addition, the organization of teams involved in the Project Controls were mostly Cost Controller and Scheduler type (Table 17).

Table 14

Distribution of Functions Procured During Execution of Projects (%) (Question 28)

Materials	Equipment	Subcontractors	Direct Labor
28.1	27.3	24.8	19.8

Table 15

Distribution of New Technology Use in Projects (%) (Question 30)

Yes	No
36.1	63.9

Table 16

Distribution of Level of Familiarity with the New Technology or Process Used During Design and Execution Phases of the Project (%) (Question 31)

High	Medium	Low
28.6	57.1	14.3

Table 17

Organization of Teams Involved in the Project Controls (%) (Question 32)

Cost Controller and Scheduler	Project Controller (Who does both)
80.6	19.4

Various levels of organizational hierarchy were observed in controlling the projects (Table 18). The various hierarchies ranging from very simple one-level controller to complex seven-level controllers were involved in controlling the project. However, the simple two-level project controller structure was observed for project controls in most of the projects. Furthermore, the number of reporting lines for project controllers varies widely considering internal or external project stakeholders (Table 19). This ranges from the simple reporting line to only one project stakeholder to a number of reporting lines up to the 12 project stakeholders. However, it was observed that for most of the projects, the reporting line for project controllers involved two project stakeholders.

Table 18

Statistics on the Hierarchy Levels of Controllers Involved in Controlling the Projects (Question 33)

Minimum	Maximum	Modal group	Average	Median	Standard deviation
1.0	7.0	2.0	2.4	2.0	1.2

Table 19

Statistics on Various Internal or External Sequential Reporting Functions Reporting Lines for Project Controllers (Question 34)

Minimum	Maximum	Modal group	Average	Median	Standard deviation
1.0	12.0	2.0	3.3	3.0	2.5

The most common observed weekly workload in projects is 50 to 60 hours (Table 20). It was also found that the number of equivalent full-time employees (FTE) worked to control the status of the projects varies widely and ranges from zero or less than one to 21 or more personnel in a single project (Table 21 & Table 22).

Table 20

Projects' Distribution by Weekly Workload (%) (Question 29)

40 hrs./week	50 to 60 hrs./week	24 Hours, 7 days a week	Other weekly workload
22.2	75.0	0.0	2.8

Table 21

Projects' Distribution by Number of Equivalent Full-Time Employees (FTE) Involved in Project Control (%) (Question 36)

None or less than 1	1	2	3	4	5	6
5.6	16.7	13.9	11.1	13.9	2.8	11.1

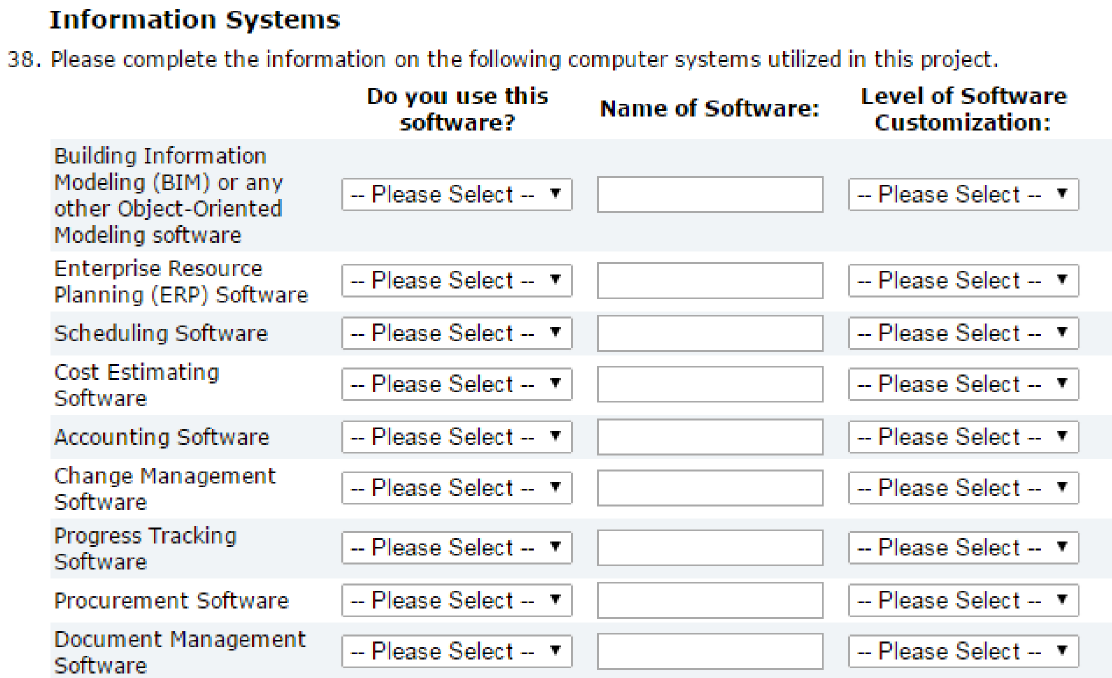
Table 22

Projects' Distribution by Number of Equivalent Full-Time Employees (FTE) Involved in Project Control (%) (Question 36) (Continued)

7	8	9	10	11 to 15	16 to 20	21 or more
0.0	2.8	0.0	5.6	0.0	13.9	2.8

5.4 Project Information Systems

Survey 1 inquires about the information systems used on projects as shown in Figure 3. The use of the software, the name and type of the tool used, and the level of customization were questioned to assess the level of information system use on these projects. The level of customization was either out of the box, customized, or in-house.



Information Systems

38. Please complete the information on the following computer systems utilized in this project.

	Do you use this software?	Name of Software:	Level of Software Customization:
Building Information Modeling (BIM) or any other Object-Oriented Modeling software	-- Please Select --		-- Please Select --
Enterprise Resource Planning (ERP) Software	-- Please Select --		-- Please Select --
Scheduling Software	-- Please Select --		-- Please Select --
Cost Estimating Software	-- Please Select --		-- Please Select --
Accounting Software	-- Please Select --		-- Please Select --
Change Management Software	-- Please Select --		-- Please Select --
Progress Tracking Software	-- Please Select --		-- Please Select --
Procurement Software	-- Please Select --		-- Please Select --
Document Management Software	-- Please Select --		-- Please Select --

Figure 3. Survey 1 question 38 on use of information systems

Various software packages were used for the project management functions surveyed. It was shown that software utilization across the industry varied substantially with numerous softwares reported for each and different project functions (Table 23 & Figure 4). For instance, it can be observed that for Progress Tracking, 16 distinct software programs are being used (See Table 23 & Figure 4). The only functions with prevailing software systems used include Building Information Modeling (BIM), Enterprise Resource Planning (ERP), and Scheduling Softwares (See Table 23 & Figure 4).

Table 23

Composition of Information Technology Tools (Question 38)

Function	No. of Systems Used
Building Information Modeling (BIM)	3
Enterprise Resource Planning (ERP) Software	4
Scheduling Software	5
Cost Estimating Software	10
Accounting Software	9
Change Management Software	12
Progress Tracking Software	16
Procurement Software	8
Document Management Software	15

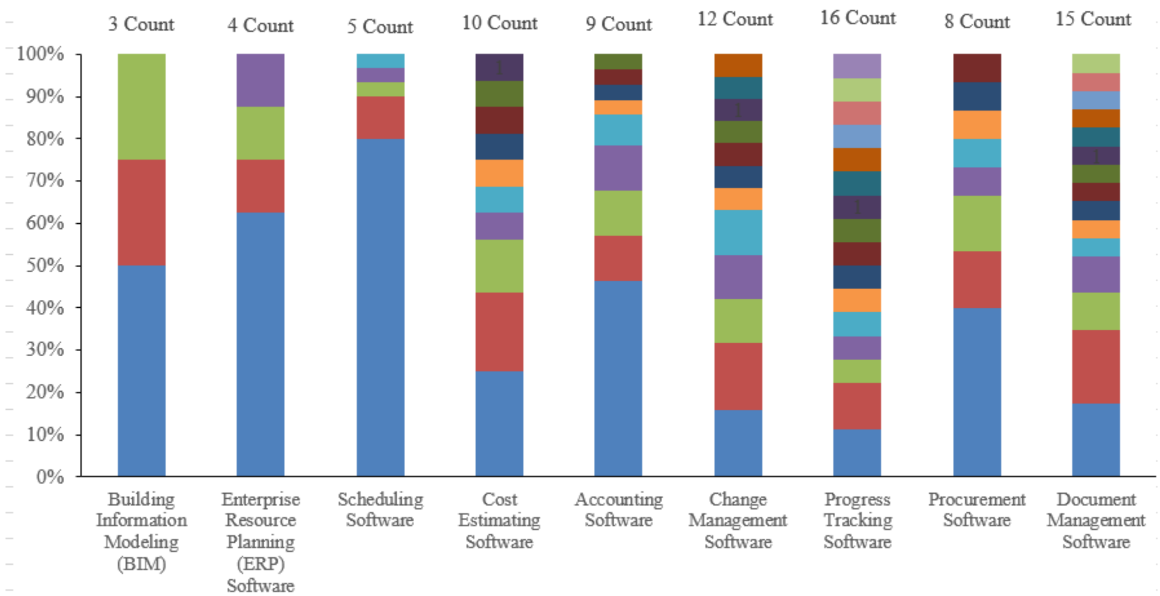


Figure 4. Composition of Information Technology Tools, Numbers Above Each Column Represent the Number of Systems Used, each Colored Box Represents a Specific Software, and the Length of each Colored Box Represents the Pervasiveness of each Software (Question 38).

Both contractors and owners extensively used information systems for cost estimating, scheduling, accounting, change management, progress tracking, procurement, and document management (Table 24 & Figure 5). Conversely, ERP software was usually used in owners' projects. BIM software was mostly not used by both owners and contactors. It is possible that the utilization of software packages for procurement, BIM, or ERP might be higher because the respondents were mostly project managers who are potentially not aware of the systems used on their projects.

Table 24

Response Rate for Software Utilization (Count and Percentage of Responses)

Functions	Respondents	
	Count	Percentage
Building Information Modeling (BIM)	7	18%
Enterprise Resource Planning (ERP) Software	10	26%
Scheduling Software	33	87%
Cost Estimating Software	23	61%
Accounting Software	34	89%
Change Management Software	25	66%
Progress Tracking Software	22	58%
Procurement Software	20	53%
Document Management Software	25	66%

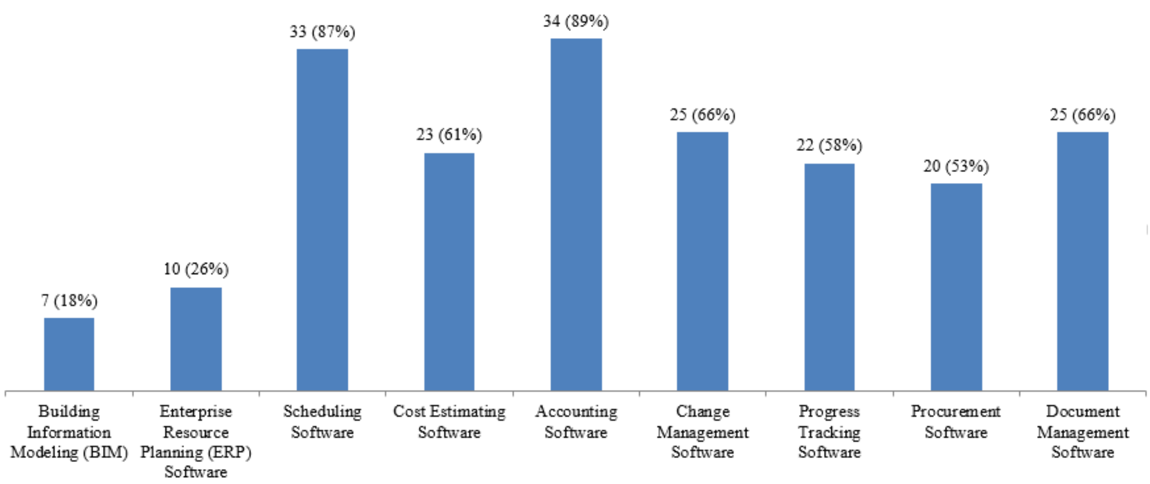


Figure 5. Response Rate for Software Utilization (Count and Percentage of Responses) (n=38).

Other findings indicate that cost estimating, accounting, procurement, document management, and ERP software are generally procured outside the company and then customized in-house (Table 25). However, the change management and progress tracking software are typically developed inside the company (Table 25). Conversely, software for scheduling and BIM are usually procured as out-of-the-box packages (Table 25).

Table 25

Level of Customization for Software Packages (% of responses) for All Projects, Owner and Contractor Submitted Projects (Question 38)

	All projects			Owner Submitted Projects			Contractor Submitted Projects		
	In-house	Out of Box	Custo-mized	In-house	Out of Box	Custo-mized	In-house	Out of Box	Custo-mized
BIM	16.7	50.0	33.3	0.0	66.7	33.3	33.3	33.3	33.3
ERP	22.2	0.0	77.8	28.6	0.0	71.4	0.0	0.0	100.0
Scheduling Software	20.7	65.5	13.8	7.1	71.4	21.4	33.3	60.0	6.7
Cost Estimating Software	23.8	33.3	42.9	27.3	45.5	27.3	20.0	20.0	60.0
Accounting Software	15.6	18.8	65.6	12.5	18.8	68.8	18.8	18.8	62.5
Change Management Software	52.2	8.7	39.1	60.0	10.0	30.0	46.2	7.7	46.2
Progress Tracking Software	52.4	14.3	33.3	50.0	20.0	30.0	54.5	9.1	36.4
Procurement Software	30.0	15.0	55.0	25.0	16.7	58.3	37.5	12.5	50.0
Document Management Software	28.0	28.0	44.0	18.2	36.4	45.5	35.7	21.4	42.9

Some software were used more pervasively than others and sometimes reported to be used in not only one project controls function but in several. In this sample, SAP is the mostly used software for accounting, change management, procurement, and ERP. Excel and Primavera are generally used for cost estimating, scheduling, and progress tracking in this sample. Also, for the data gathered Livelink and Smartplan are usually used for document management and BIM respectively.

It must be noted that a number of survey respondents indicated that they had integrated two or more software programs to develop an integrated information system for project control and management.

5.4.1 Building Information Modeling (BIM)

The use of information systems for BIM is not widely used in this sample. Only about 30% of all respondents implied that they use BIM software in project management. This statistic is quiet unusual, considering that the use of BIM is expected to be a growing trend in the construction industry. It must be noted here that the data for this survey was collected through project managers and project controllers who are usually not involved in the design phase. Considering that BIM is usually used in the design phase, there is the possibility that the respondents may not actually know it is use in the design phase and only provide their guess as to the use of BIM on their projects. Here it can be also noted that in addition to design, the information from BIM is used to track the progress of the trades and to develop quantity-based total installed cost estimates. Table 26 shows the various types of software used for BIM and used by survey respondents.

Table 26

Building Information Modeling Software Used by Survey Respondents (n=7)

Software Technology	Count
Smartplan	2
Revit	1
Microstation	1

Currently, most of the BIM software is purchased from the professional software developing companies for in-house use by construction firms (Table 27).

Table 27

Respondents' Opinions on BIM Software Customization (by % of Responses) (n=6)

In House	Out of Box	Customized
16.7	50.0	33.3

5.4.2 Enterprise Resource Planning (ERP)

ERP is a suite of integrated business management packages, and the analysis of the survey results reveal that only 26% of all respondents use some sort of ERP software. The construction industry is fragmented; thus, the use of ERP software for construction business management and corresponding integration of various information systems is uncommon in this sample. Table 28 shows the various types of software used for ERP by the survey respondents.

Table 28

Enterprise Resource Planning Software Used by Survey Respondents (n=10)

Software Technology	Count
SAP	5
Vision	1
Primavera P6	1
Oracle	1

It is noticeable that SAP is the most popular ERP system in this sample. Currently, most of the ERP software packages are purchased from the professional software developing companies and then customized in-house by construction firms for their use (Table 29).

Table 29

Respondents' Opinions on ERP Software Customization (by % of Responses) (n=9)

In House	Out of Box	Customized
22.2	0.0	77.8

5.4.3 Scheduling

The use of information systems for project scheduling is a major part of this sample. More than 87% of all respondents implied that they use one or more software for scheduling. Table 30 shows the various types of software used by the survey respondents for project scheduling.

Table 30

Scheduling Software Used by Survey Respondents (n=33)

Software Technology	Count
Primavera	24
Microsoft Project	3
Oracle	1
Safran	1
Sure Track	1

It is evident that currently Primavera is the dominant software tool for scheduling in this sample. Presently, most of the scheduling software is purchased from the professional software developing companies for in-house use by construction firms (Table 31).

Table 31

Respondents' Opinions on Scheduling Software Customization (by % of Responses) (n=29)

In House	Out of Box	Customized
20.7	65.5	13.8

5.4.4 Cost Estimation

More than 61% of respondents implied that they use one or more software for cost estimation. Table 32 shows the various types of software used by survey respondents for project cost estimation.

Table 32

Cost Estimation Software Used by Survey Respondents (n=23)

Software Technology	Count
Excel	4
Icarus	3
Oracle	2
Aspen K-base	1
Deltek	1
MC2	1
Viewpoint	1
Timberline	1
Vision	1
Database (general)	1

It is noticeable that at present Excel, Icarus, and Oracle are the most common software solutions for cost estimation in this sample. Currently most of the cost-estimating software is purchased from the professional software-developing companies and then customized in-house by construction firms for their use (Table 33).

Table 33

Respondents' Opinions on Cost Estimating Software Customization (by % of Responses) (n=21)

In house	Out of box	Customized
23.8	33.3	42.9

5.4.5 Accounting

All respondents implied that they use one or more software for accounting purposes. Table 34 shows the various types of software used by survey respondents for project accounting.

Table 34

Accounting Software Used by Survey Respondents (n=34)

Software Technology	Count
SAP	13
Oracle	3
Viewpoint	3
Vision	3
Timberline	2
Deltek	1
Maximo	1
Cobra	1
Prolog	1

It is clear that SAP is the dominant tool for accounting in this sample. Oracle, Viewpoint, and Vision are other popular software programs in this sample for use in project accounting. Most of the accounting software is purchased from the professional software-developing companies and then customized in-house by construction firms for their use (Table 35).

Table 35

Respondents' Opinions on Accounting Software Customization (by % of Responses) (n=32)

In House	Out of Box	Customized
15.6	18.8	65.6

5.4.6 Change Management

More than 66% of all respondents implied that they use one or more software for change management. Table 36 shows the various types of software used for project change management by survey respondents.

Table 36

Change Management Software Used by Survey Respondents (n=25)

Software Technology	Count
SAP	3
Prolog	3
Oracle	2
Microsoft Excel	2
Viewpoint	2
Epoch OCMS	1
Vision	1
Deltek	1
Microsoft Access	1
Legacy	1
Database (general)	1
Other (Customized)	1

The results show that there are myriad software packages being used for this project controls function in this sample. Presently, most of the change management software is developed in-house by construction firms for their use (Table 37).

Table 37

Respondents' Opinions on Change Management Software Customization (by % of Responses) (n=23)

In House	Out of Box	Customized
52.2	8.7	39.1

5.4.7 Progress Tracking

More than 58% of respondents implied that they use one or more software programs for progress tracking. Table 38 shows the various types of software used for project change progress tracking by the survey respondents.

Table 38

Progress Tracking Software Used by Survey Respondents (n=22)

Software Technology	Count
Primavera	2
Microsoft Excel	2
Wellview	1
Safran	1
Proteus	1
Spreadsheets (general)	1
WMS	1
Viewpoint	1
Vision	1
PTT	1
Dekker	1
Microsoft Project	1
Oracle	1
Customized Curves	1
Database (general)	1
Other	1

As can be seen from the table above, the software utilization for progress tracking has no software dominating the scene in this sample; many of these software programs are developed in-house (Table 39).

Table 39

Respondents' Opinions on Progress Tracking Software Customization (by % of Responses) (n=21)

In House	Out of Box	Customized
52.4	14.3	33.3

5.4.8 Procurement

The use of information systems for project Procurement Management is moderately popular in this sample. Less than 53% of all respondents implied that they use one or more software programs for procurement management. Table 40 shows the various types of software used for project procurement management by the survey respondents.

Table 40

Procurement Management Software Used by Survey Respondents (n=20)

Software Technology	Count
SAP	6
Viewpoint	2
Vision	2
Microsoft Excel	1
Oracle	1
Federal Procurement System	1
Legacy system	1
Database (general)	1

It is noticeable that, at present, SAP is a popular tool for procurement management in this sample. The other popular procurement management software packages are Viewpoint and Vision. In this sample, most of the procurement softwares are purchased from the professional software-developing companies and then customized in-house by construction firms (Table 41).

Table 41

Respondents' Opinions on Procurement Management Software Customization (by % of Responses) (n=20)

In House	Out of Box	Customized
30.0	15.0	55.0

5.4.9 Document Management

More than 66% of all respondents implied that they use one or more software programs for document management. Table 42 shows the various types of software used by the survey respondents for project document management.

Table 42

Document Management Software Used by Survey Respondents (n=25)

Software Technology	Count
Livelink	4
Newforma	4
Sharepoint	3
Prolog	2
SAP	1
Intergraph	1
Legacy system	1
Opentext	1
Oracle	1
Box.com filing	1
VPC	1
Viewpoint	1
Documentum	1
Customized	1

There are myriad software packages being used for document management in this sample as evidenced by the table above. The software packages are mostly purchased and then customized in-house (Table 43).

Table 43

Respondents' Opinions on Document Management Software Customization (by % of Responses) (n=25)

In House	Out of Box	Customized
28.0	28.0	44.0

5.4.10 Integration of Information Systems

In Survey 1 or the batch mode survey, an open-ended question (question 39) asked about the integration of the aforementioned information systems. Only 40% of respondents implied that they have connected two or more information systems in their array of software packages and information systems. A reason for this could be the fragmented nature of the capital projects industry and the inability of the project manager/controller to identify each system individually and track whether various information systems are connected or not.

The current practice of information system integration varies widely. Organizations in this survey usually customize and integrate their systems at very rudimentary levels. The most common practice is the integration of two types of information systems, such as a cost estimation system connected to the accounting system, an accounting system connected to the change management system, a progress tracking system connected to the scheduling system, a scheduling system connected to the cost estimation system, and so on. Some organizations in this survey purchase one business information system suite and customize it for multiple purposes. The one such example is the use of SAP for enterprise resource planning, accounting, change management, procurement, and document management; those various modules of SAP are interconnected. The other example is the customization of the viewpoint information system suite for document management, procurement, progress tracking, accounting, cost estimation, and change management purposes. Sometimes information system integration is accomplished in a way that data from one information system is used to feed into several other information systems. In this case, a number of information systems are connected to one master information system. Thus, if there is a new input or update of information in the master information system, there will be corresponding updates in other information systems. In addition, information systems are customized and interconnected to access via one interface. Also, it is perceived from this survey that at this time the integration of BIM and project control information is not popular and is still at its infancy stage for this sample (question 40).

5.5 Reporting Frequencies

The analysis of the collected data revealed that today's industry practices can best be described as utilizing a "batch mode" operation for both the data collection and reporting of project controls data and documentation. A consequence of this practice is that the ultimate decision maker is often referencing information that is not truly reflective of current project status. False conclusions may be reached and corrective actions often come too late. One of the key findings of this research is that the research team was able to identify the median a) age of data reported to the project manager and b) the age of the data reported to the ultimate client or project authority for each of the project controls functions previously described. In order to do so and as previously stated, the project controls functions were comprehensively defined by the research team.

The research found that the time lag, due to common process encumbrances, is often as long as two months or greater between when data is collected until the corresponding information is reviewed by the ultimate decision maker. The across-the-board batch reporting mode results in a poor controls capability and negative consequences with respect to the ability to make timely and informed decisions. Reporting frequencies are not designed to satisfy the decision makers at the different levels of management. Figure 6 illustrates the existing "batch condition" prevalent in the construction engineering industry today, in which the same data is sequentially reported at different layers within key stakeholder organizations, with older data at each reporting function. Lag in reporting results in the decision-making authority acting on old and unreliable information and effectively sustains a reactive response to problems. Thus, scenarios were documented in which the upper management of the client organization utilized information based on six-month old data. Many companies were found that reported scope and quality issues within 24 hours because of the huge impact on construction. Another finding is that functions closer to day-to-day operations are reported more frequently than business functions, such as forecasting, scheduling, and estimating.

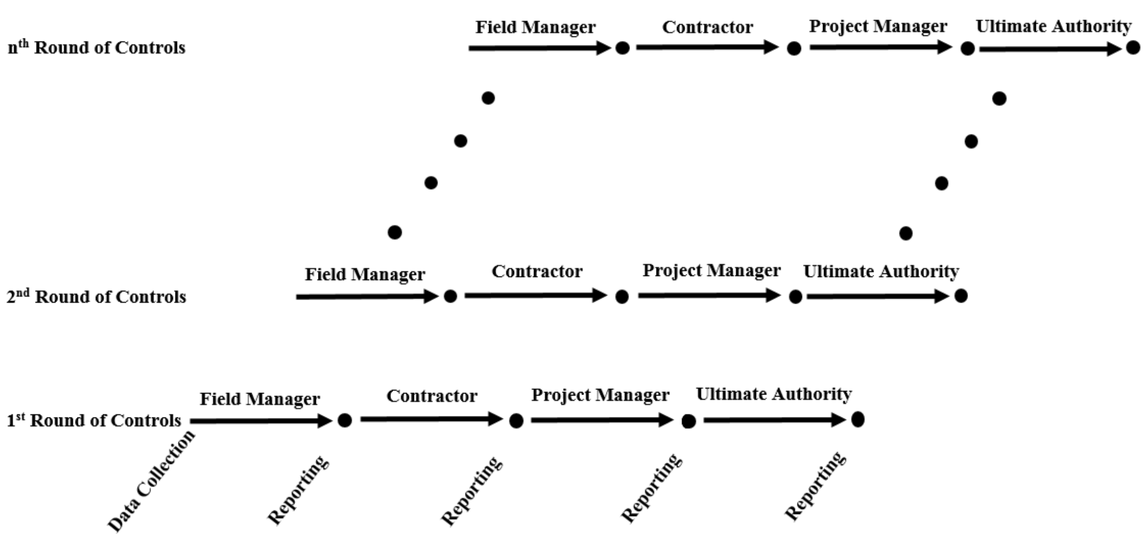


Figure 6. Reporting Lag Across Organizational Functions.

The survey looked at the frequency of data collection and reporting to feed various project control functions at four phases: engineering design, procurement, construction, commissioning, and startup. For each function of the phases of the project, two reporting frequencies have been reported—one for the Project Manager (PM) and the other for the Ultimate Authority (UA) or the stakeholder. The blue arrows in Figures 7 to 18 represent the median time it takes for raw data to be reported as information to the PM, and the red arrows represent the time it takes to report to the project UA. Figures 7 to 18 and Tables 44 to 47 present the median time lag that data is reported to the PM and UA for all projects, owner submitted projects, and contractor submitted projects.

For each of the four project phases, it was desired to know how data on various control functions are collected and reported in terms of cost, schedule, scope, and quality. Age of data reporting was checked at two levels: reporting to Project Manager (PM) and reporting to Ultimate Authority (UA) at the client organization. The data on use of control functions at various phases of the project were collected from projects by both owners and contractors. Here, it may be noted that not all the owners and contractors from the 38 projects provide feedback on all the control functions they used.

It was observed that there is variation from owners' and contractors' perspective in age of data reporting. This fact was considered in reporting various project control functions in this section. Therefore, in addition to analytical results on various control functions for all projects, the analytical results for projects by owners and contractors were also reported in Tables 44 to 47. This will help the reader understand the magnitude in which the practice of data collection and reporting for various cost control functions in owners' projects differs from contractors' projects.

Table 44

Median Reporting Frequencies for the Engineering Phase in Days (All Projects) (Questions 47 to 55)

	All Projects		Contractor Submitted Projects		Owner Submitted Projects	
	PM	UA	PM	UA	PM	UA
Cost						
Plan Baseline/Control Budget	15	15	15	15	15	15
Monitor Committed Cost	15	15	7	15	15	15
Monitor/Control Change Order Cost	7	15	7	15	7	15
Monitor Budget	15	15	7	30	15	15
Monitor Actual Expenditures	15	15	7	15	15	15
Plan/Control Estimate to Complete for current eng. phase	15	30	7	30	15	30
Monitor Engineering Performance - performed vs planned	15	15	7	15	15	30
Plan/Monitor Risk Analysis	30	30	15	30	30	30
Estimate the Total Engineering Cost for all engineering phases	30	30	30	30	30	30
Monitor Accounts Payable	30	30	30	30	15	30
Monitor Accounts Receivable	30	30	30	30	15	30
Monitor/Control estimated Total Installed Cost	30	30	30	30	15	15
Schedule						
Develop Baseline Schedule	15	15	7	15	15	15
Monitor Major Milestone Progress	15	15	7	15	15	15
Estimated Time to Completion	15	15	15	15	15	15
Scope						
Develop Control Scope	7	15	7	7	7	15
Monitor Change Order Status	7	15	15	15	7	15
Monitor CO impact to project schedule and cost	15	15	15	11	7	15

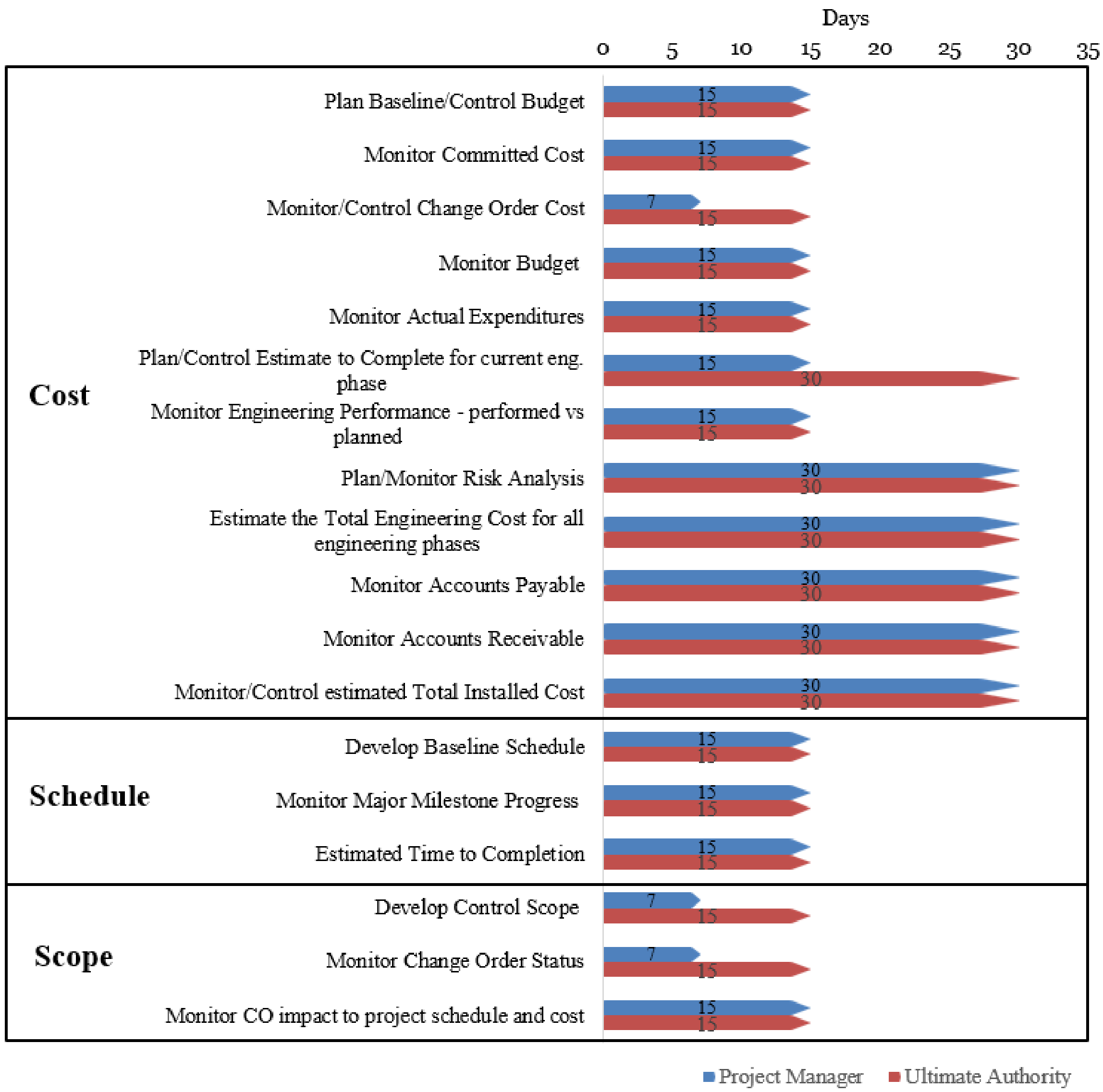


Figure 7. Median Reporting Frequencies for the Engineering Phase In Days (All Projects) (Questions 47 to 55)

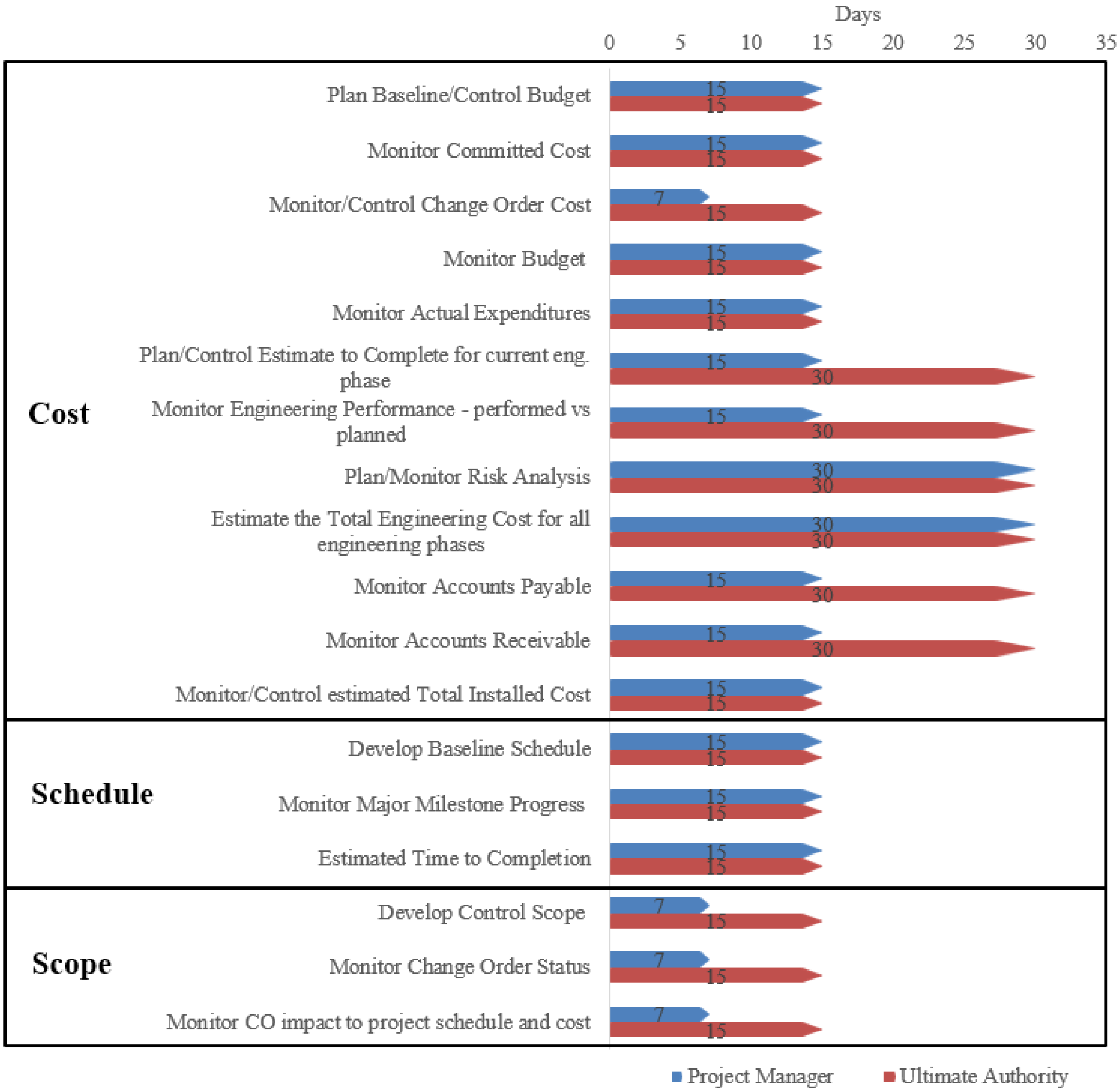


Figure 8. Median Reporting Frequencies for the Engineering Phase In Days (Owner Projects) (Questions 47 to 55)

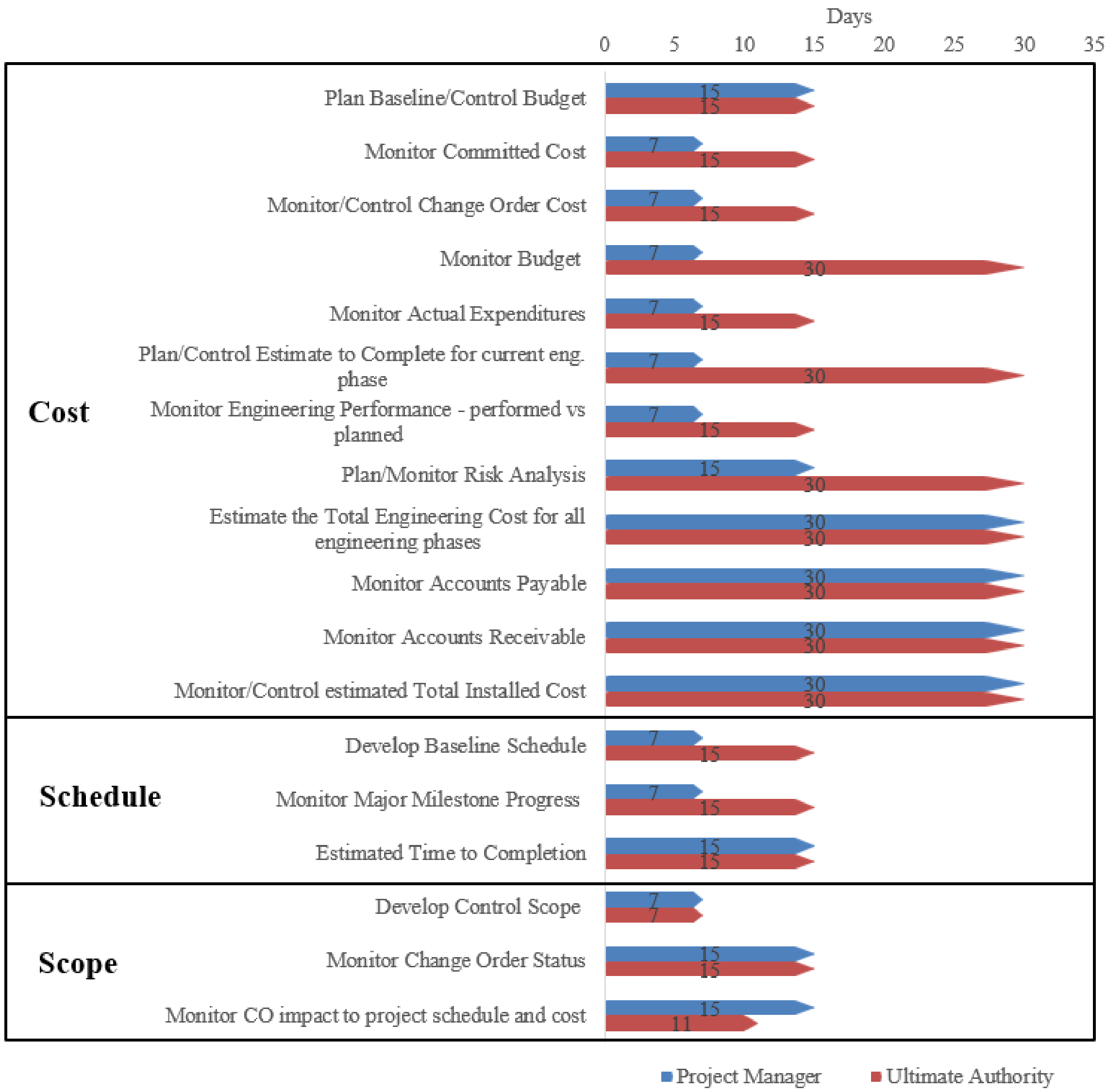


Figure 9. Median Reporting Frequencies for the Engineering Phase In Days (Contractor Projects) (Questions 47 to 55)

Table 45

Median Reporting Frequencies for the Procurement Phase in Days (All Projects) (Questions 57 to 68)

	All Projects		Contractor Submitted Projects		Owner Submitted Projects	
	PM	UA	PM	UA	PM	UA
Cost						
Plan Baseline/Control Budget	7	30	7	7	15	30
Monitor Committed Cost	15	30	15	15	15	30
Monitor/Control Change Order Cost	7	30	15	15	7	30
Monitor Budget	15	30	15	15	15	30
Monitor Actual Expenditures (actual eng. cost to date)	15	30	15	15	15	30
Plan/Control Estimate to Complete for all phases	15	30	15	15	15	30
Monitor Procurement Performance - performed vs planned	15	15	15	15	15	30
Plan/Monitor Risk Analysis	15	30	15	15	30	30
Monitor Accounts Payable	15	30	30	30	15	30
Monitor Accounts Receivable	15	30	30	30	15	30
Monitor/Control estimated Total Installed Cost	15	30	15	30	15	30
Schedule						
Develop Baseline Schedule	15	15	7	7	15	30
Monitor Major Milestone Progress	15	15	15	30	7	15
Estimated Time to Completion	15	15	15	30	15	15
Scope						
Develop Control Scope	15	30	7	30	15	30
Monitor Bid Tracking Log	7	30	15	30	7	30
Monitor Purchase Order Tracking Log	15	30	15	30	15	30
Monitor Change Order Status	15	30	15	30	15	30
Monitor Change Order Impact to Project Schedule and Cost	15	30	15	30	15	30
Quality						
Quality Tests and Inspections	7	7	7	7	7	15
Quality and Turnaround of Requests for Information (RFIs)	7	7	7	7	7	30

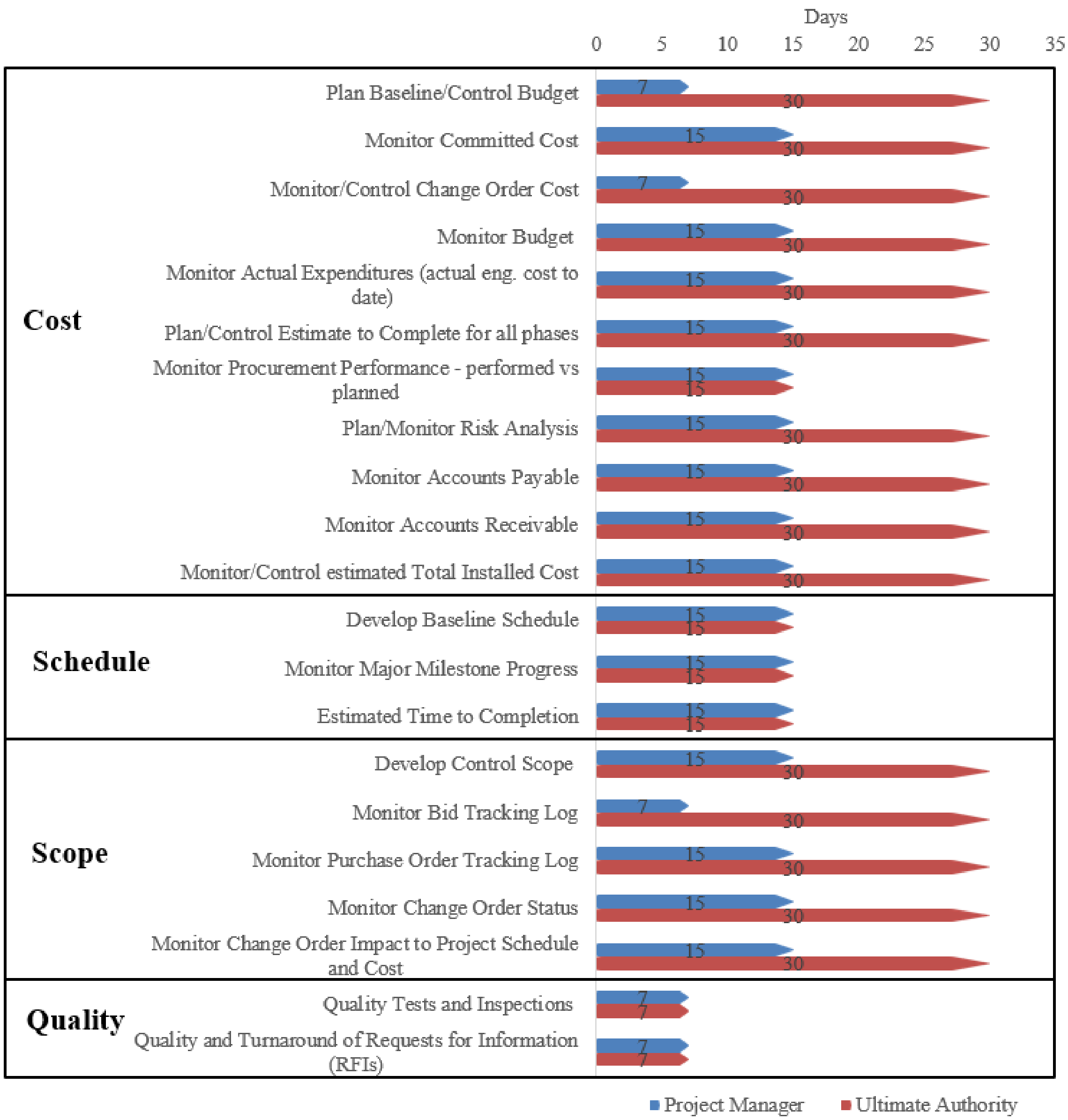


Figure 10. Median Reporting Frequencies for the Procurement Phase In Days (All Projects) (Questions 57 to 68)

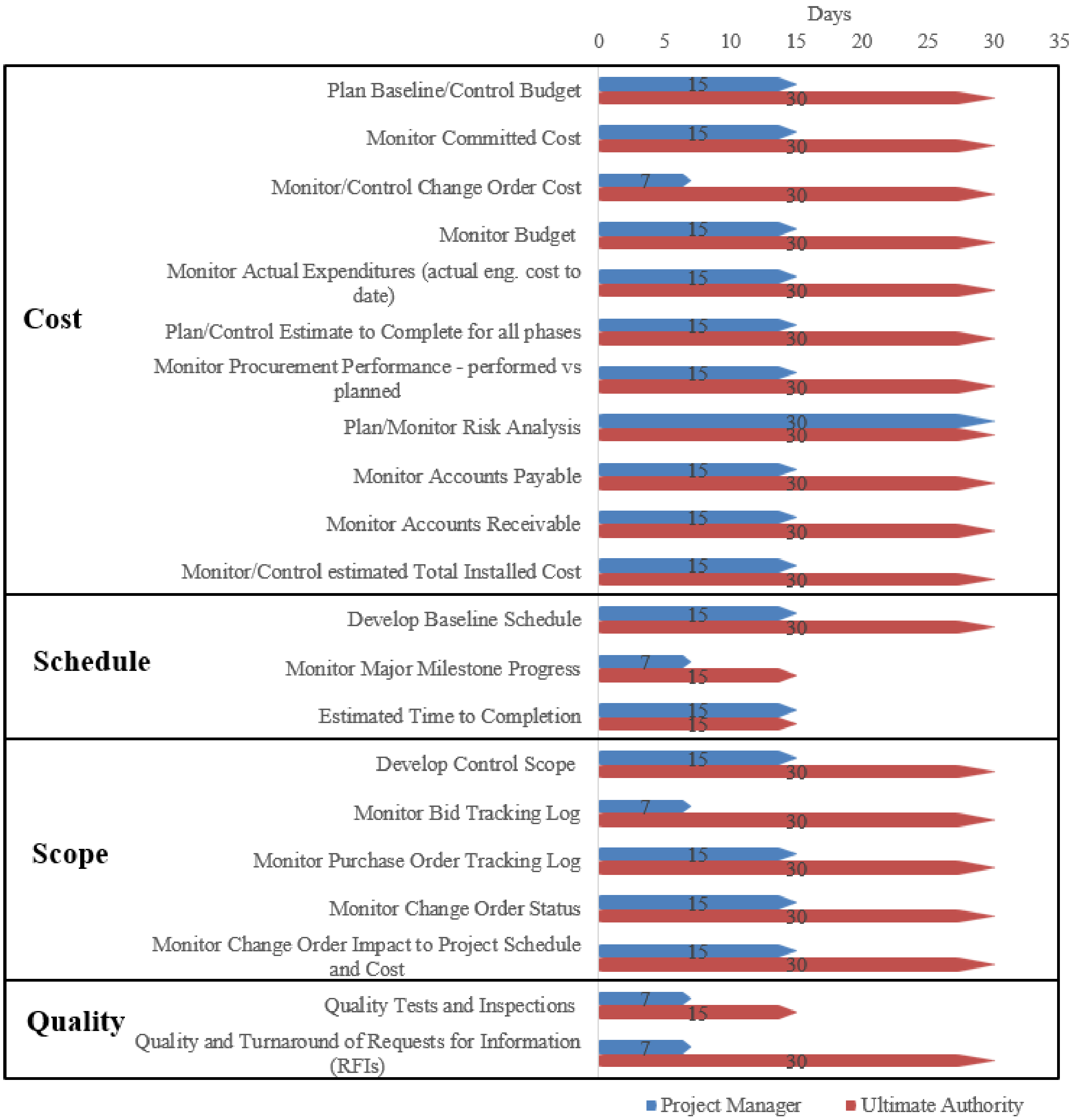


Figure 11. Median Reporting Frequencies for the Procurement Phase In Days (Owner Projects) (Questions 57 to 68)

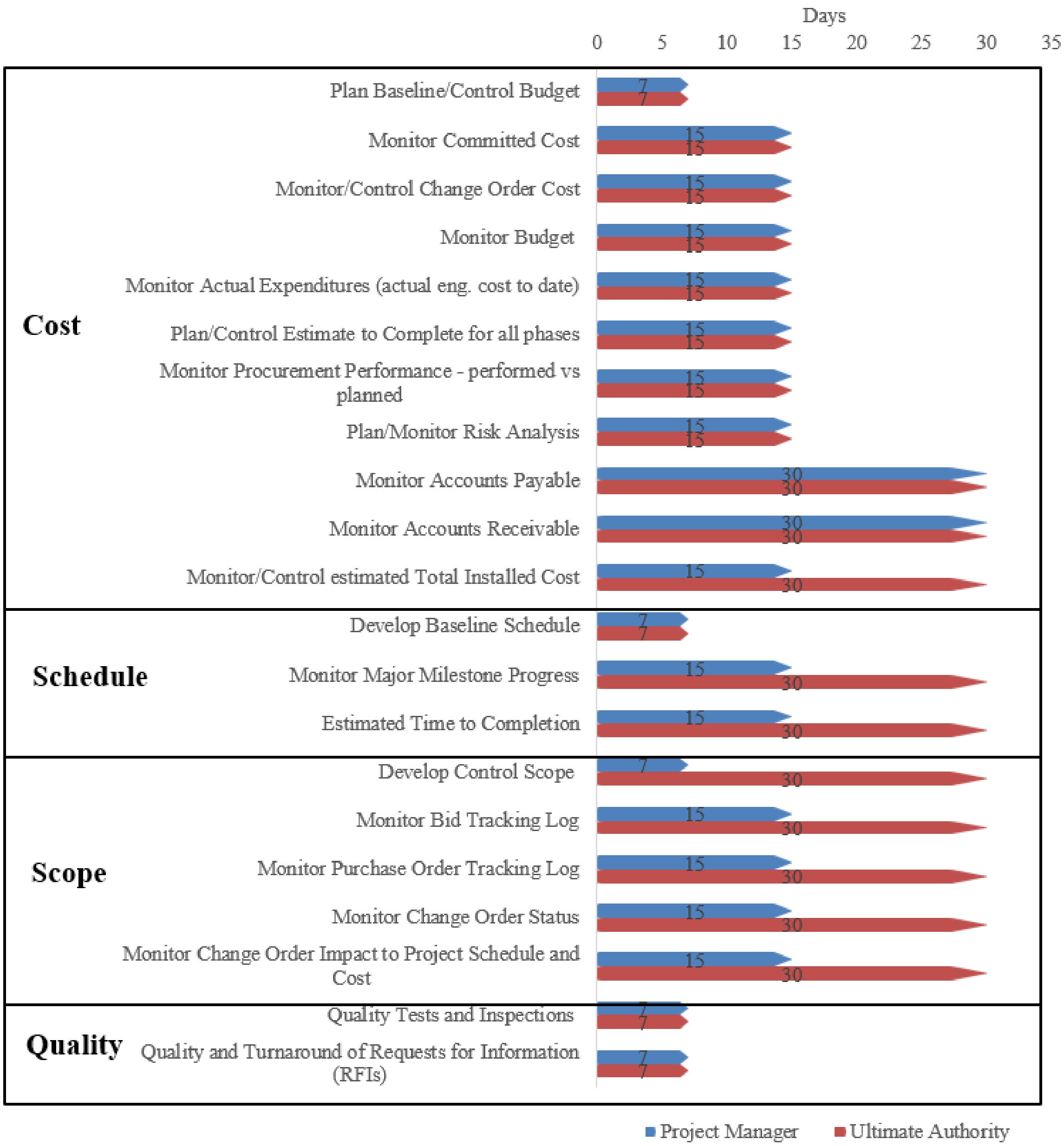


Figure 12. Median Reporting Frequencies for the Procurement Phase In Days (Contractor Projects) (Questions 57 to 68)

Table 46

Median Reporting Frequencies for the Construction Phase in Days (All Projects) (Questions 70 to 81)

	All Projects		Contractor Submitted Projects		Owner Submitted Projects	
	PM	UA	PM	UA	PM	UA
Cost						
Plan Baseline/Control Budget	15	30	15	30	15	15
Monitor committed Cost	15	15	15	30	15	15
Monitor/Control Change Order Cost	7	15	7	30	7	15
Monitor Budget (Baseline Plus Approved Change Order)	7	15	7	30	15	15
Monitor Actual Cost/Expenditures to Date	7	15	15	30	7	15
Estimate Total Installed Cost	15	30	15	30	15	30
Monitor Construction Performance Measurement - performed vs planned	7	15	7	30	7	15
Monitor Risk Analysis	15	30	15	30	30	30
Monitor Accounts Payable	7	30	7	30	7	15
Monitor Accounts Receivables	7	15	7	30	11	15
Schedule						
Develop Baseline Schedule	15	30	15	30	15	30
Monitor Major Milestone Progress	7	15	15	15	7	15
Estimated Time to Completion	15	15	15	15	7	15
Scope						
Develop Control Scope	7	15	15	30	7	15
Monitor Change Order Status	7	15	7	15	7	15
Monitor Change Order Impact to Project Schedule and Cost	15	15	15	15	15	30
Quality						
Quality Tests and Inspections	7	7	7	7	7	15
Quality and Turnaround of RFIs	7	7	7	7	7	30
Rework Hours / Costs	7	15	15	15	7	15
Design Omissions	7	15	15	15	7	15
Design Errors	7	15	15	15	7	15
Constructability	7	15	7	30	7	15

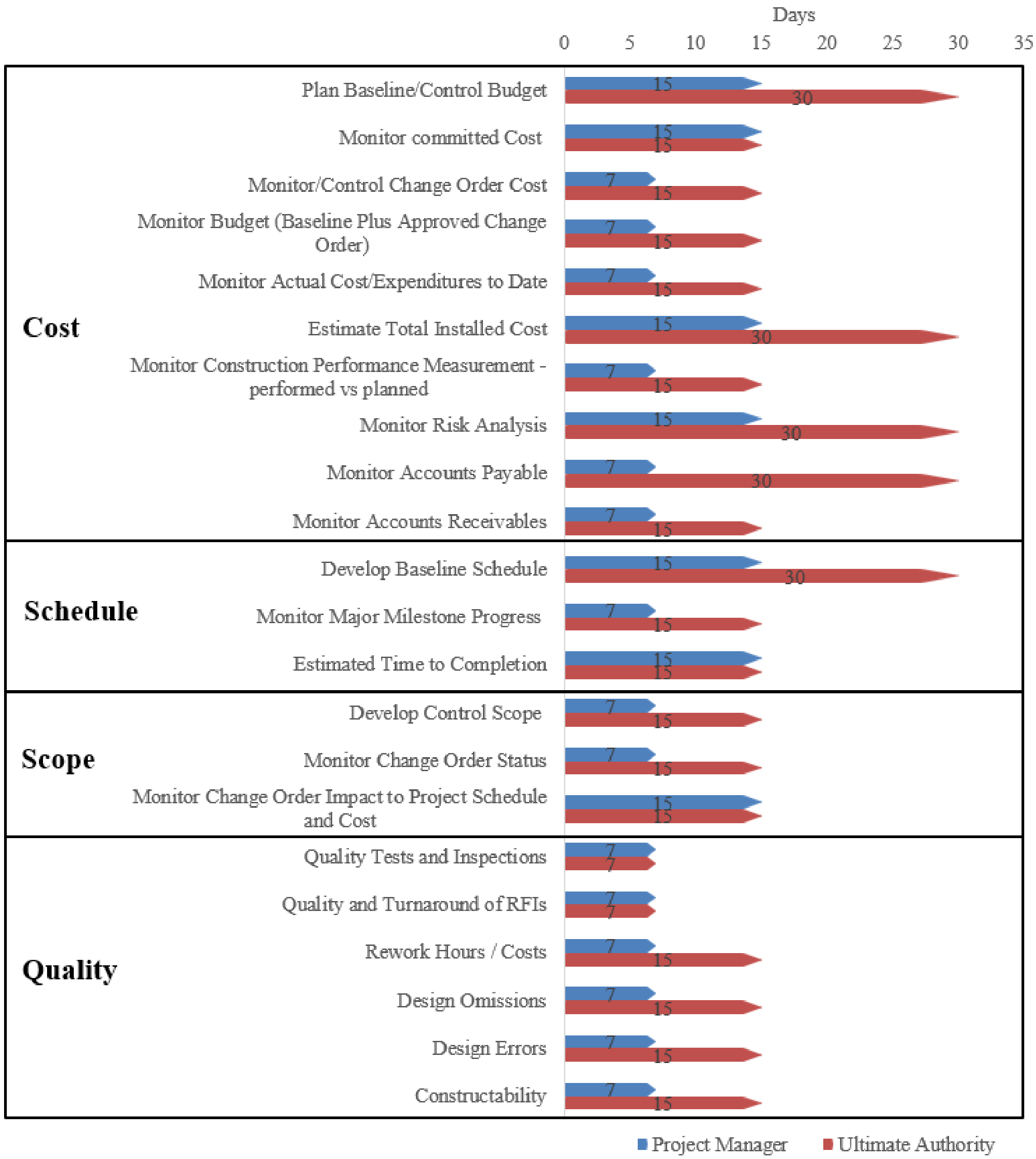


Figure 13. Median Reporting Frequencies for the Construction Phase In Days (All Projects) (Questions 70 to 81)

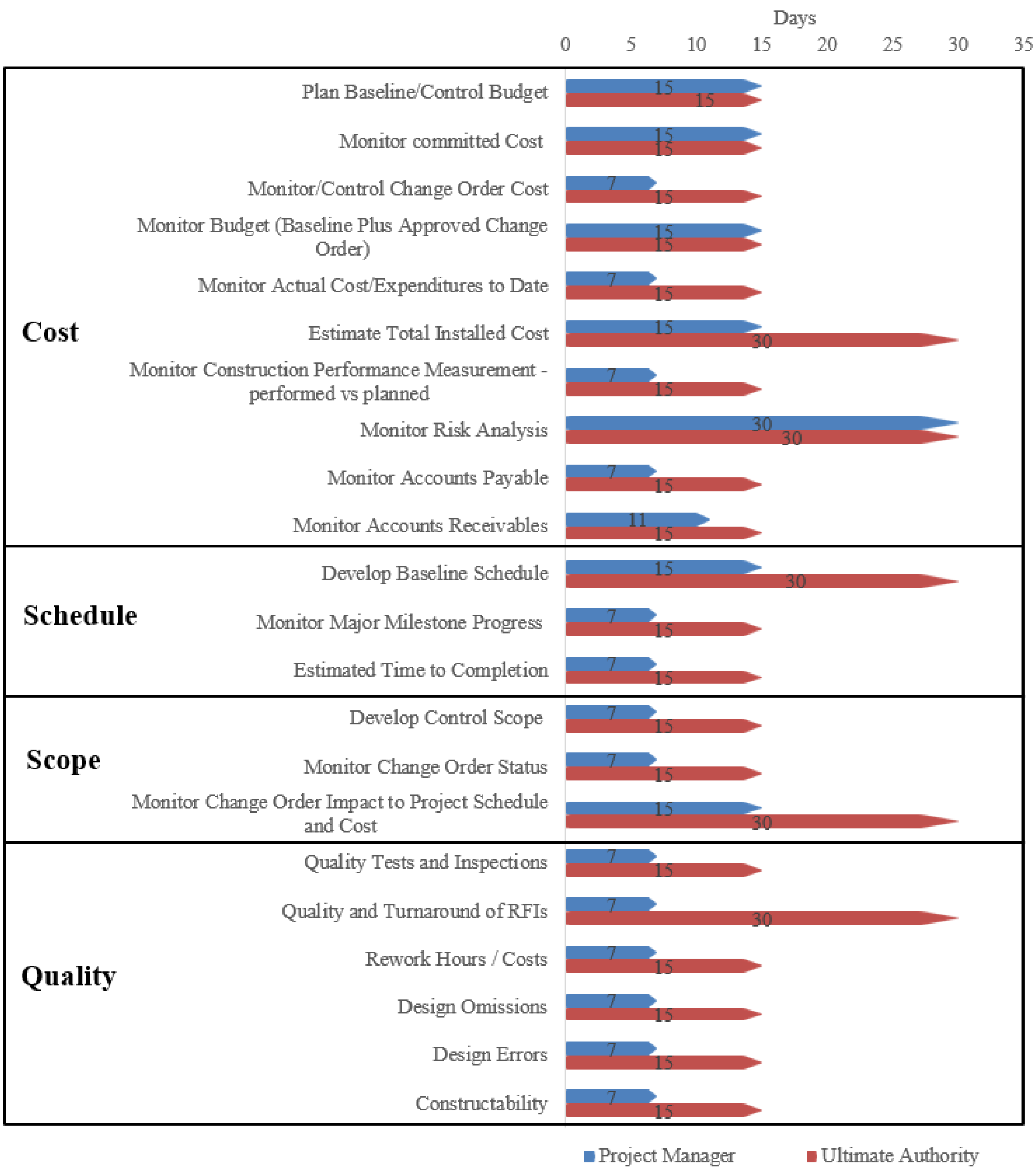


Figure 14. Median Reporting Frequencies for the Construction Phase In Days (Owner Projects) (Questions 70 to 81)

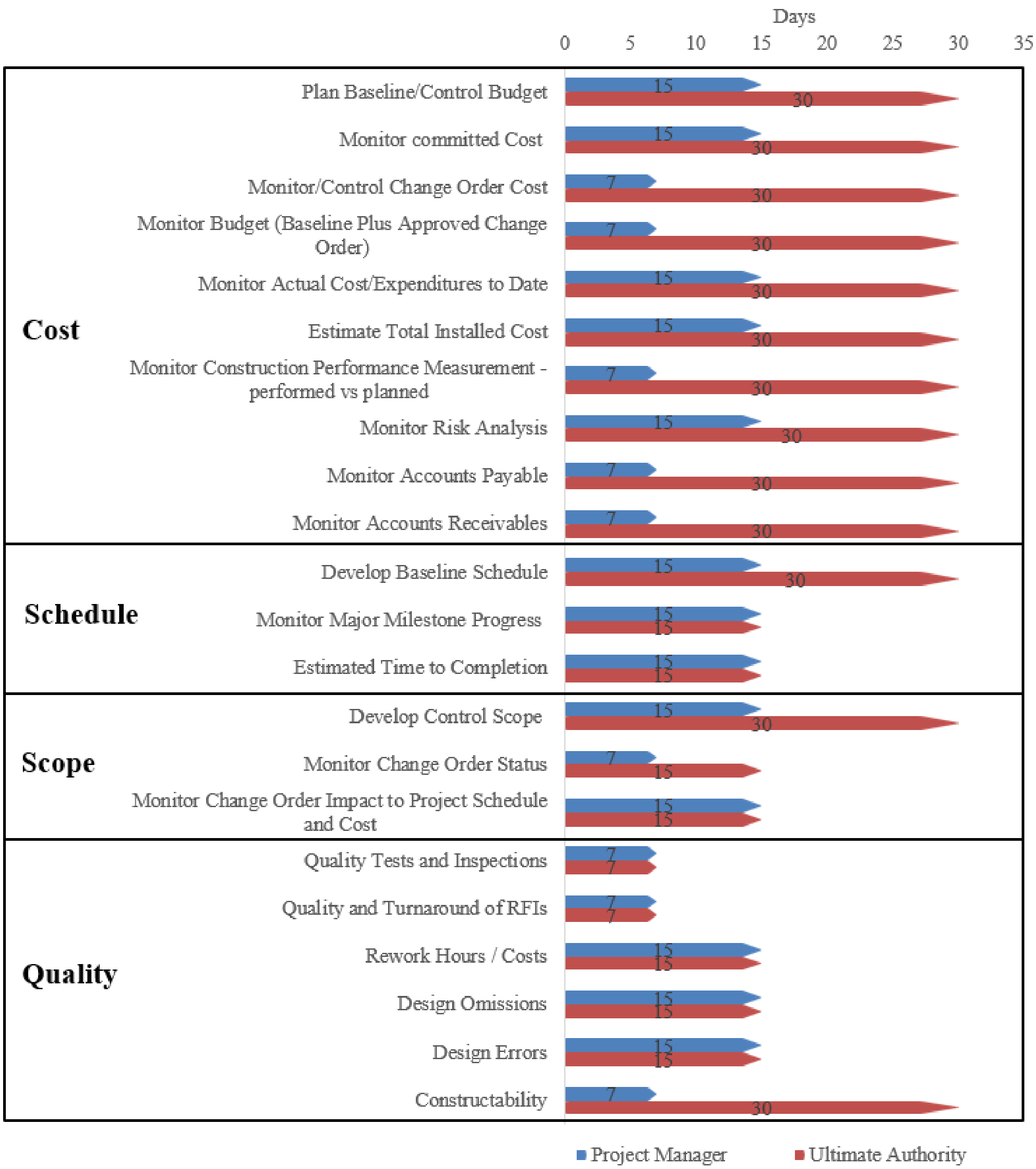


Figure 15. Median Reporting Frequencies for the Construction Phase In Days (Contractor Projects) (Questions 70 to 81)

Table 47

Median Reporting Frequencies for the Commissioning and Startup Phase in Days (All Projects) (Questions 83 to 94)

	All Projects		Contractor Submitted Projects		Owner Submitted Projects	
	PM	UA	PM	UA	PM	UA
Cost						
Plan Baseline/Control Budget	7	7	15	30	7	7
Monitor committed Cost	15	15	15	30	15	7
Monitor/Control Change Order Cost	7	15	30	30	7	7
Monitor Budget	15	15	30	30	7	7
Monitor Actual Cost/Expenditures to Date	15	15	15	30	7	7
Estimate Total Installed Cost	15	15	30	30	15	7
Monitor Commissioning Performance Measurement - performed vs planned	15	15	30	30	15	15
Monitor Risk Analysis	15	15	15	30	15	15
Monitor Accounts Payable	15	15	30	30	7	15
Monitor Accounts Receivables	15	15	30	30	15	15
Schedule						
Develop Baseline Schedule	7	7	7	7	15	15
Monitor Major Milestone Progress	7	15	7	15	15	15
Estimated Time to Completion	15	15	7	15	15	15
Scope						
Develop Control Scope	15	15	7	7	15	15
Monitor Change Order Status	7	15	7	15	7	15
Monitor Change Order Impact to Project Schedule and Cost	15	15	7	15	15	15
Quality						
Quality Tests and Inspections	7	7	1	7	7	7

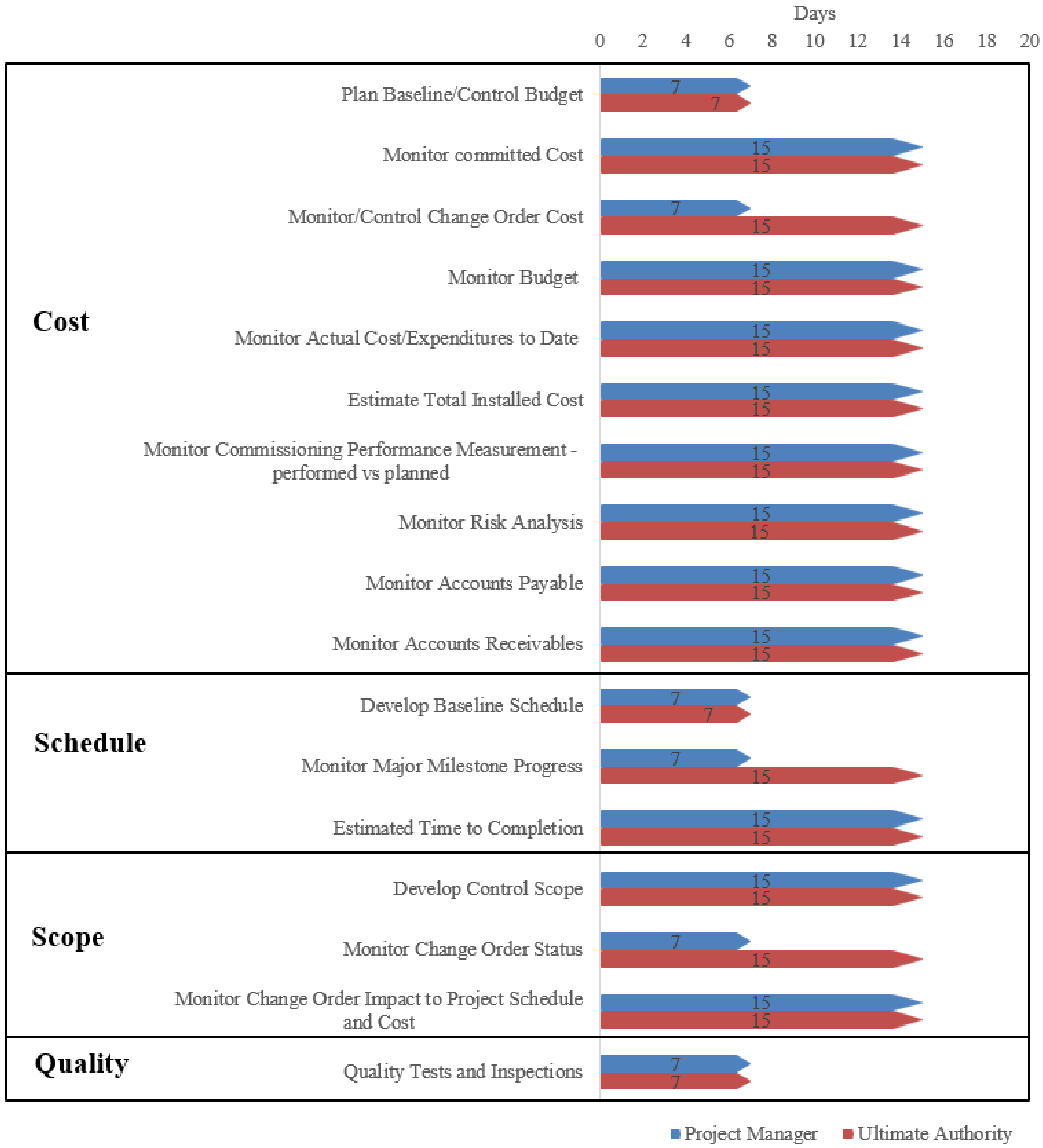


Figure 16. Median Reporting Frequencies for the Commissioning and Startup Phase In Days (All Projects) (Questions 83 to 94)

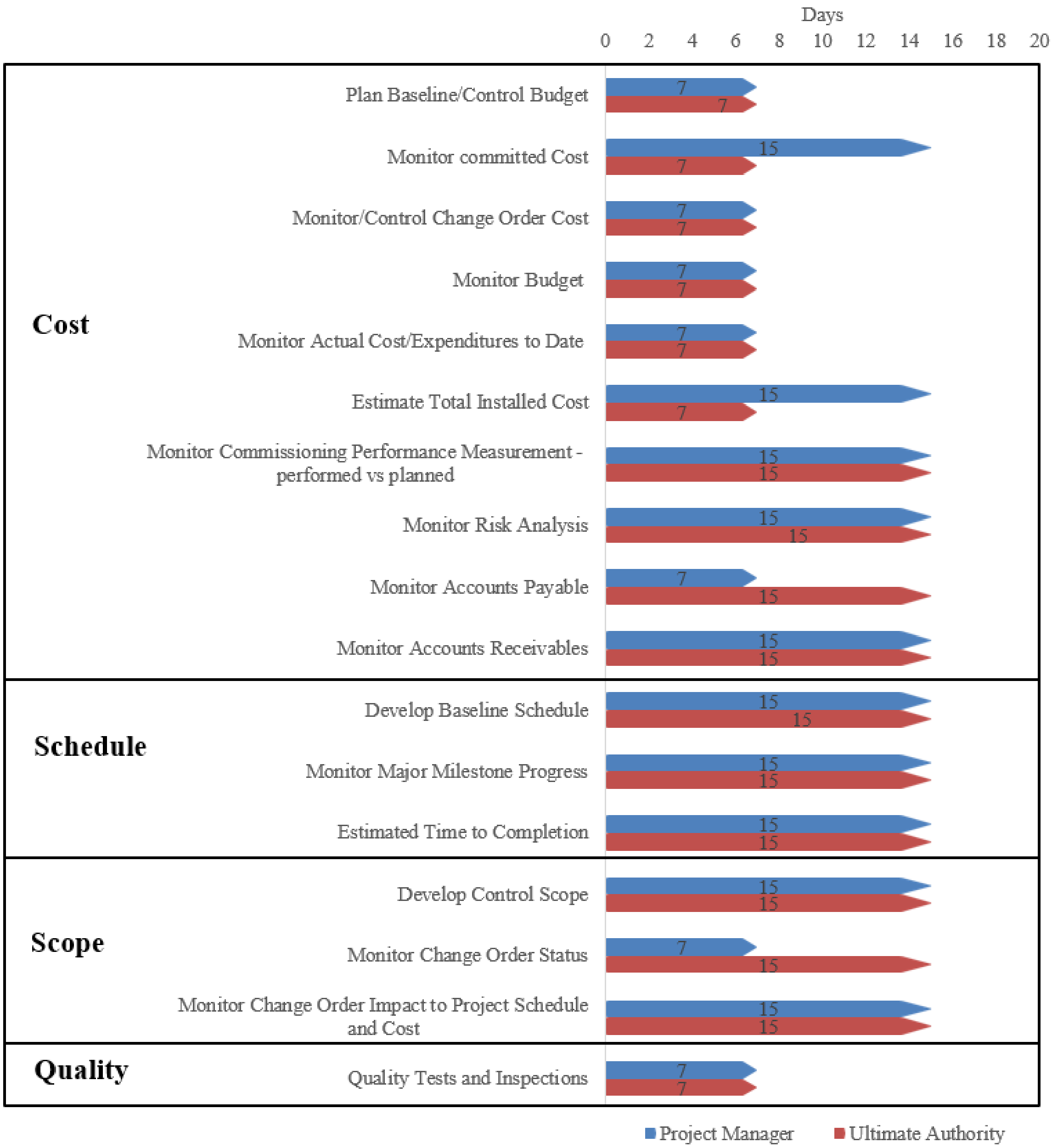


Figure 17. Median Reporting Frequencies for the Commissioning and Startup Phase In Days (Owner Projects) (Questions 83 to 94)

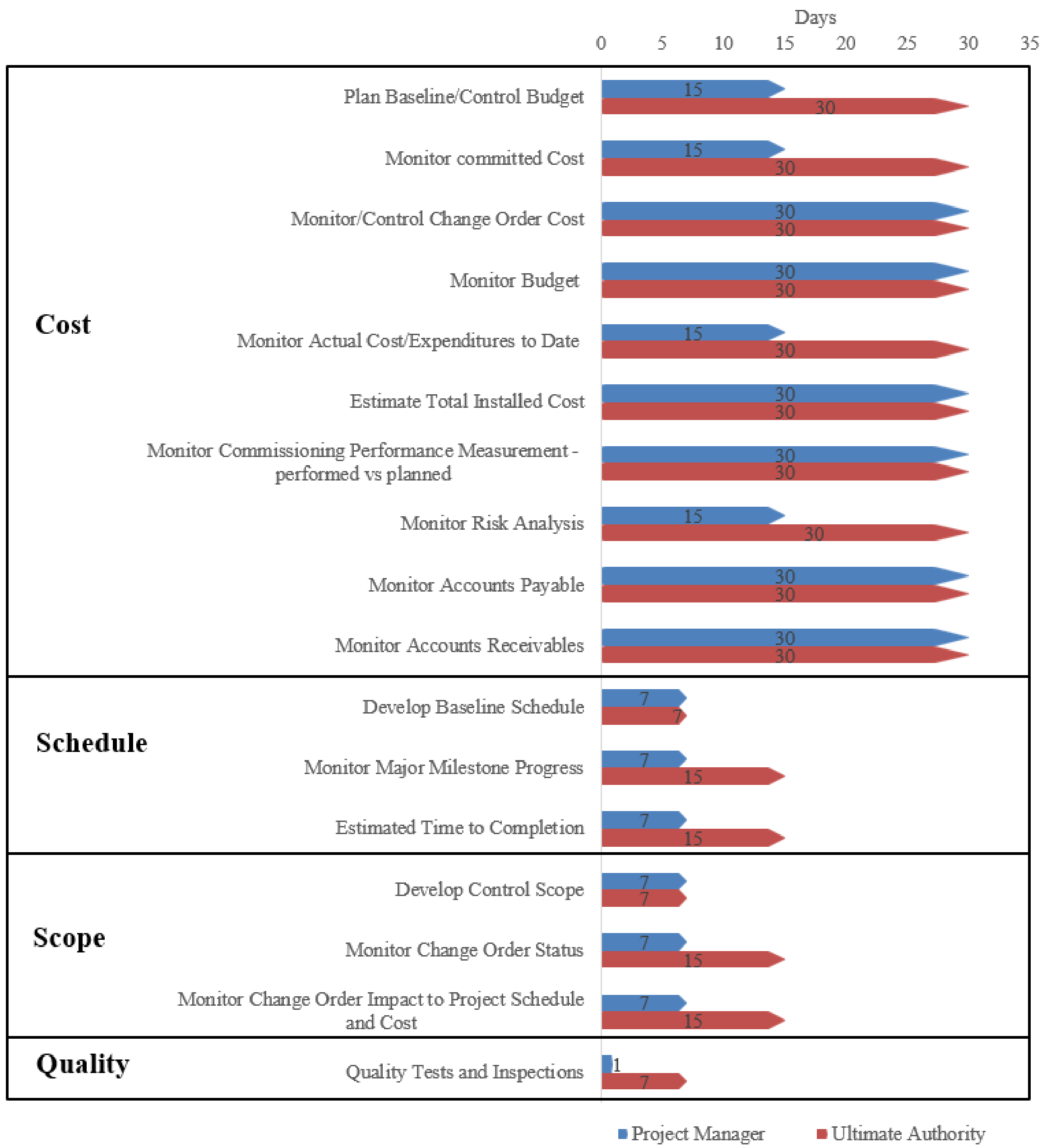


Figure 18. Median Reporting Frequencies for the Commissioning and Startup Phase In Days (Contractor Projects) (Questions 83 to 94)

CHAPTER 6: IMPLEMENTATION STRATEGIES FOR INSTANTANEOUS PROJECT CONTROLS

In order to satisfy objective 2 of this research study or the assessment of IPC practices, a multiple case study research approach was adopted. In this chapter, the interview design, case study data collection, and insights gained from the case studies are presented; a brief description of each case study is written; also a detailed description of the practices and constructs identified through the multiple case study is included, finally, the validation of the case studies is explained. The primary contributor to the insights and findings in this chapter was CII Research Team 316 members.

6.1 Design/Prequalification

To document current industry practices for instantaneous project controls, a multiple case study with a holistic line of inquiry that incorporated a variety of perspectives was conducted. The research team carefully selected cases to ensure they would present a variety of trends, patterns, and clusters of data on instantaneous communication of information.

Ninety minutes were allotted for each interview, which were facilitated by a structured interview protocol consisting of 16 open-ended and structured questions. The interview protocol addressed issues related to business rationale, data collection/reporting, technologies, benefits and barriers, implementation cost and schedule, and maintenance, among others. The open-ended design of the questions allowed for the pursuit of specific threads of discussion or expanded the scope of a conversation. The interview protocol questions are presented in Table 48. The interview protocol was sent to these organizations ahead of time through email (see Appendix III).

The interviews were held either by phone or face-to-face with interviewees within the higher managerial positions and experts affiliated with companies regarded as leaders within their respective industries. The interviewed companies belonged not only to the construction sector but also to the information technology, manufacturing, and aerospace industries.

Table 48

Interview Protocol

#	Interview Question
1.	Can you give us an example where your operation has systems and processes that rely on instantaneous information? Please describe how the information is used in your operation.
2.	What was the original business problem or business objective when you established the system?
3.	Is your system linked to other corporate systems, e.g., ERP system?
4.	Are your clients or suppliers feeding or using the information for your system?
5.	How often do you input data or how often is data updated automatically?
6.	How frequently do you report out using the system?
7.	Who on the team uses the data and what decisions do they make using the data, e.g., manufacturing schedules, etc.?
8.	What are the primary benefits of the system?
9.	What were the original barriers to adopting the system?
10.	What are current challenges you experience with the system?
11.	How do you motivate or incentivize your clients/suppliers to update data and utilize instantaneous data?
12.	If systems and processes were available, what other real-time data collection and feedback would you implement?
13.	Do you have any plans (short-term or long-term) to enhance your system?
14.	Who is your technology partner on this system, or are there industry leading vendors in this space?
15.	Can you provide a system flow diagram that shows how information is input processed and out using the system?
16.	How much cost or FTEs are necessary to maintain the system on an annual basis?

The case studies fulfilled the need for an external cross-validation since it enabled the identification of common characteristics, traits, and trends from multiple industry, management, and technical perspectives. The research team used these case studies to identify high-impact practices and strategies that help companies in the path to implementation of IPC.

6.2 Interviews/Data Collection

Research team members identified 10 companies among CII member and non-CII members that had at least one instantaneous controls function and invited these companies for interviews. In all but one case, the interviewed organizations were represented by at least two individuals, and the interviewees were always upper management (with the exception of Case Study 2). This upper-management perspective accounts for an organizational-based focus for the implementation of instantaneous project controls (as opposed to a project-based focus). The only exception to this organizational focus was Case Study 2 since the interviewees were project managers and controllers. It stands alone in its project-centered focus on implementing instantaneous controls. A summary of the case studies can be seen in Table 49.

Many of the interviews were recorded and transcribed, and key words were identified and logged. A coding process was implemented to identify common nodes, constructs, trends using key words, and clustering of data.

Table 49

Summary of Case Studies

Case no.	Sector	Organizational Role	Instantaneous Function(s)
1	General Construction	Construction Manager	Reporting: Project Cost, Procurement, and Change Management
1	General Construction	Construction Manager	Reporting: Portfolio Financials
2	Oil and Gas	Owner	Reporting: Project Cost and Schedule Progress
3	General Construction	Software Provider	Automation: Payment Transactions
4	General Construction	Software Provider	Information Integration: Project Information
5	Automobile	Automotive Manufacturer	Monitoring: Production and Quality
6	Building Facilities	Contractor	Reporting: Craft Labor Productivity
7	General Energy	Engineering & Contractor	Reporting: Cost and Schedule for Pipeline Infrastructure Projects
8	Aerospace	Owner	Information Integration: Project Information
9	Technology Manufacturing	Owner	Reporting: Planning, Budgeting, and Scheduling for Capacity Planning Decisions
10 (i)	Engineering Design	Software Provider	Reporting: Craft Labor Productivity
10 (ii)	Engineering Design	Software Provider	Reporting: Design Engineering Progress

It became evident that despite sparse functions displaying instantaneous characteristics not a single construction company adopted IPC across its organization. However, it was found that many organizations, from diverse industries, had successfully implemented certain process improvements or innovative strategies resulting in an instantaneous capability in one or more aspects of project controls. The only company that came close to the notion of instantaneous was an automotive manufacturing company that implemented instantaneous monitoring of production systems, although reporting was done at specific frequencies, typically monthly or more. However, the floor or manufacturing line manager could see in real-time the manufacturing status. After sorting, structuring, and analyzing the multiple case studies gathered, nine constructs were identified that were categorized into three categories of organizational behavior, control functions, and advanced systems and technologies.

6.3 Insights

The analysis of the case studies provided three important insights; first, the relationship between implementation of instantaneous reporting with lean construction; second, how monitoring is often implemented (rather than controls); and third, how the scope of instantaneous reporting/controls can substantially vary, depending on the monitored metric or function. These insights are further discussed in this section.

6.3.1 A Lean Perspective

Lean principles were originally developed and implemented in the manufacturing sector; these principles aim to reduce variability during the production process. As is discussed in Case Study 5, the manufacturing industry strives to instantaneously control the assembly line in order to reduce variability in productivity and quality. In the manufacturing industry, not all functions are monitored in real-time. Although the assembly line functions are monitored in an instantaneous manner, business-related metrics are reported in a batch mode. These business-related metrics might include the number of manufactured products or work hours per unit of product, which are usually reported in a batch mode at specific reporting intervals and usually range from weekly to monthly frequencies based on the specific metric being monitored.

Controls on a production line is more of a real-time monitoring process, where issues are quickly detected and instantly corrected. In this real-time monitoring process no reporting of information occurs meaning that the assembly line is captured and transmitted in real time without being analyzed. After issues are detected, in order for immediate corrective actions to be taken, usually the worker at the assembly line is responsible for making decisions and implementing any needed corrective actions, which might include stopping the production line altogether until the issue is resolved. Transmitting the authority to the worker allows issues that interrupt workflow stability and affect quality to be addressed in a prioritized manner. Monitoring and decision-making at the worker level allows issues to be addressed instantly and before they accumulate into bigger problems. To further emphasize, the assembly line is monitored in real-time but business-related metrics, such as schedule, cost, or forecasting functions, are reported at specific frequencies, which may not be necessarily in an instantaneous manner. This method of monitoring and controlling is to facilitate timely decision-making and prevent negative impacts from late or uninformed decisions.

6.3.2 Monitoring Construction Versus Controlling Projects

After assessing the case studies in this research, it became clear that the monitoring and controls policy as implemented by the manufacturing sector is slowly but definitively being embraced by the capital projects industry. Instant monitoring and prioritized control policies are being employed in the construction industry in order to gain global competitive advantage. Capital projects are comprised of highly variable processes; if issues during these processes are not addressed in a timely manner, they could quickly compound and result in significant negative impacts.

As indicated previously, some of the case studies are from outside the construction industry. It can be observed from these industries and their instantaneous monitoring and prioritized reporting that the construction industry must also shift toward such a policy of on-demand or timely project operations status monitoring. As will be discussed in further detail, some of the case studies revealed that operating functions, such as field operations, quality, craft labor productivity, and progress functions among others, are being monitored in real-time while business functions and project performance measures are not. Functions critical to project success, such as quality, should be instantaneously monitored. The case studies revealed that both the manufacturing and construction industries monitor similar metrics related to operations in real-time. These operation functions include productivity, quality, and workflow which affect variability.

6.3.3 Proportional Scope and Implementation Effort

Another observation made during the case studies is that each controls function has a different scope that affects the implementation effort needed for their instantaneous monitoring or controls. For instance, some functions include project cost and schedule status reporting, which are large in scope and require the implementation of relational databases at the project or organizational levels or the development of integration interfaces between software systems. Some functions that are limited in scope include tracking payments, change management, and craft labor productivity, which require less effort to instantaneously monitor or control. It is worthwhile to explore the relationship between the scope of a real-time function and the resources needed and ease of its implementation. Generally, it was observed that the broader the scope of the function, the larger the amount of resources needed for its implementation—whether these resources be time, money, or manpower. Long-term and extensive project control functions require that leadership be on board and provide the resources necessary for the implementation of such controls. While many smaller or less mature organizations can benefit from implementing instantaneous monitoring or control functions due to the limited resources they offer, more mature organizations can invest in more resources to implement more extensive instantaneous control functions.

Case Study 3, which will be further described in detail, describes an automated payment function as an example control function with limited scope that requires less investment in terms of time, effort, and money. As explained in Case Study 3, this payment function requires less than a month for implementation and minimal in-house resources. All companies interviewed expressed an interest in implementing an instantaneous controls function, but the suggestion to these companies is to consider the resource requirements and payoff from implementing such real-time monitoring functions.

6.4 Case Studies

In this section, each case study is briefly explained as to the industry context, business driver for the instantaneous function being reported, the barriers and benefits to its implementation, and resource requirements.

6.4.1 Case Study 1: Daily Reporting of Project Cost, Procurement, and Change Management/Updated Portfolio Financials

The interviewed organization is a construction consulting and management services organizations providing services to owner organizations throughout the project life cycle. During the interview, the organization outlined their web-based enterprise project portfolio management solution. This project portfolio management solution enables the seamless sharing of document and information across key stakeholders. The solution allowed for the transmittal of cost and procurement data at a daily reporting frequency available to the owner, updates of owner's financials by means of XML or comma delimited type of file integration, and integration of vendor data, among others.

The web-based solution incorporates many business intelligence tools that enable automatic checking for compliance with laws and regulations. Since everyone has access to their needed data, everyone became accountable, and transparency became a norm.

The business intelligence rules needed workflow development, which was resource-intensive to develop. Shifting toward this new system was met with some resistance from accounting and financial personnel. The system is not yet integrated with BIM and GIS information, something the company is diligently working toward. It was mentioned that two full-time employees are needed to maintain the system.

6.4.2 Case Study 2: Daily Project Cost and Schedule Updates

The interviewed organization operates in the oil and gas sector. This case is the only case where the unit of analysis is the project, since the interviewees were project managers and project controllers. The reported is a schedule-driven shutdown project that was plagued by uncertainty; the project had been carefully planned for eight months and was successfully executed in 55 days against a hard startup production deadline. The work was done intensely around the clock through two shifts by 5,500 workers. The data collection was done manually through 200 field managers (100 per shift). The driver to employ so many field managers was that the project was crucial to the business, and every day lost meant loss of production. Also, time for corrective action was extremely limited and the scope of work was so uncertain that the company wanted to decrease risk and uncertainty and institute tight and timely controls on project progress and cost performance.

The intensive manual data collection and reporting of project information resulted in daily reporting on progress, productivity, earned hours versus planned hours, and costs. This labor-intensive controls method decreased the uncertainty on the project and resulted in the project being completed on time and on budget. Although, this controls method might have been justified on this short-period and high-risk project, its implementation will not likely be acceptable on low-risk or long-term projects due to its resource intensive nature.

6.4.3 Case Study 3: Automated Payment Transactions

A software provider for the construction industry was interviewed. The software company offers tools to support many processes and requirements, but the case study focuses on a web-based construction payment management software solution for which the company acts as a trusted third party.

Historically, subcontractors wait for payment by the owner or contractor before they release the lien waivers since they have this right, and due to the lack of transparency in the payment systems, owners and contractors would receive the lien waivers up to 30 or 45 days after payment. The software system and software company interviewed acts as a third party to whom payments are given and automatic lien waivers are released. The software system has built-in custom business processes that inquire approvers sequentially for their signatures.

This automated system has reduced disputes, caused companies to have predictable cash flow forecasts, and improved relationship between the stakeholders. Implementing such a system can take up to one month.

6.4.4 Case Study 4: Seamless Integration and Instantaneous Sharing of Project Information

In this case study, a software provider was interviewed. The software company addresses financial, project controls, and management, as well as enterprise resource planning functions. The company provides an integrated project and enterprise cloud-based solution. With the aid of a common data repository, the solution achieves seamless sharing of data to stakeholders.

A unique coding structure is developed for the use with the software solution that allows the integration of owner, contractor, and subcontractor data. This cost coding structure allows for customization of reports at different levels for various stakeholders, such as field managers or upper management. A sense of transparency and accountability is created when a common data repository is used and appropriate permissions are given to stakeholders to access this data. The cloud solution also gives real-time access to project management and controls data as soon as it is introduced in the system. The system also allows for consolidated financial data from specific projects all the way up to corporate accounts.

There are some barriers to implementation of this cloud-based system. There is a need for a cultural shift that allows individuals to accountably and transparently introduce data into the system. The upfront time and cost needed, which typically ranges from six months to two years, is another major impediment to the implementation of the system.

6.4.5 Case Study 5: Real-Time Manufacturing Monitoring and Status

A global automotive manufacturing company was interviewed. The company indicated that they are under market pressure to meet vehicle orders under stringent time and quality constraints.

A major finding in the company's monitoring and controls process is the real-time controls of their material acquisition and production processes. It was revealed that assembly line workers have the authority to make critical decisions, including stopping the production line if any quality or workflow variations occurs. Stopping the assembly line is to ensure any issues occurred are addressed before they amount to larger problems. It was revealed that the production line is monitored instantaneously, while the introduction of the material to the assembly line is updated every 15 minutes. While the monitoring of these production functions are real-time, the reporting of these operations are daily to weekly; business operation, such as cost, schedule, and forecasting, are reported in a bi-weekly and monthly bases. The instant monitoring of the production line ensures that quality issues are addressed as soon as they appear; since the worker is in charge of making such decisions, they can immediately address issues through corrective actions.

6.4.6 Case Study 6: Daily Craft Labor Progress Monitoring for Workflow Stabilization

A progressive contractor company specializing in complex technology and system-intensive building projects was interviewed. The company has a strong emphasis on stable execution of work and has indicated that bi-weekly or monthly progress reports do not suffice toward this objective. Their project controls plan is centered on development and execution of reliable budget and schedules.

The adopted workflow stabilization process by the contractor revolves around the definition of small work packages for controlling the work (typically less than 200 work hours), standardized cost code structures, and daily craft labor progress monitoring. They achieved daily reporting on work hours and quantities through manual collection of field data. Foreman had to be trained and on board regarding this intensive data-collection process. The analysis and reporting of the collected data was semi-automated using in-house software tools, but the contractor was working on automating these functions. The results from this frequent monitoring and controls process was improved project schedule and cost performance, as well as stable workflow and productivity rates.

6.4.7 Case Study 7: Daily Cost and Schedule Report for Pipeline Infrastructure Projects

The organization interviewed was an engineering/contracting company for the oil/gas, electric power, refining, and petrochemical industries. The reported instantaneous function for this contractor was the daily reporting of cost and schedule progress. The daily reporting functions were supported by manual crew-level data collection, manual data analysis, a common cost code structure among engineering and construction functions, and upper-management support. The controls process needed two FTEs per project to maintain and update cost and schedules.

The contractor mentioned project cost savings as a benefit from implementation of this daily controls process. The daily availability of cost and schedule information allows for internal benchmarking of projects through analysis of historical data.

Similar to previous case studies, there was a resistance to change by foreman who were required to report the field data. The workers and contractors needed to be trained in the collection of cost and schedule data using the correct codes and quantities.

6.4.8 Case Study 8: Seamless Integration of Project Information

The interviewed organization was an aerospace agency managing construction-related projects through its facilities and engineering department. The instantaneous aspect the organization described pertained to a new project controls system with an in-house web-accessible SQL database replacing an older legacy MS Access-based controls system. The new system and its data repository enables continuous data input, data access, and automated reporting. One FTE is required to maintain the system.

In order to ensure compliance with internal requirement and regulation workflow, logic was built into the project repository. The data is entered by lower-level managers and engineers, while the reports are reviewed by senior- or general-level management.

Benefits from implementing this new controls system are cited as: consistent project performance, improved capital allocation across the portfolio of projects, and a shift toward early disclosure of project information due to the seamless sharing of information. The barriers to implementing this new system are the resistance by the project manager to share project data due to fear of scrutiny and that there are no contractual requirements for continuous input of data, which results in some reports reporting on old data.

6.4.9 Case Study 9: Advanced Model-Based Analytics for Capacity Decisions

The interviewed company is a designer and manufacturer of technology components, such as semiconductor chips. The issue this company had was with the rapid market needs and the requirements it placed on capital project processes. For instance, historically it took five months to respond to increased manufacturing requirements in the form of a reliable work plan. An advanced model-based analytics system was developed to expedite the response placed by market needs to one month. This system is not an example of an instantaneous function but is rather presented as an example of how legacy systems can be improved substantially. The advanced model-based approach has quantities and costs built into it and supports changes in manufacturing capacity by providing a "what-if" scenario kind of analysis.

The benefits from this system are that it allows the project team to see potential requirements due to manufacturing capacity changes before any commitments are made. The what-if scenario analysis allows for comparison of options and informed decision-making. The system requires that a unique and standardized cost-coding structure be developed. There are no foreseen FTE requirements for the maintenance of the system after its development.

6.4.10 Case Study 10 (i): Daily Cost and Schedule Progress Report

The interviewed organization in this case is a provider of software solutions for capital industry organizations. This software company is research focused and reinvests 20% of its revenue back into research and development. A remote and cloud-enabled application is discussed for the data collection and field reporting on craft labor productivity and progress. The real-time data collection can be leveraged in the system to obtain earned value, progress, and productivity in real-time. The cost code structure is customizable and allows the foreman to introduce crew-level data in the system and, with the availability of wireless connection data, automatically store the data from the jobsite.

The software provider claims that one to five percent cost savings can be achieved by implementing their system. The availability of real-time data organizations can perform internal benchmarking of their projects. There is a change resistance from people who report field data, such as foreman, due to a lack of alignment and accountability; there is a need to train and realign the focus of these personnel.

6.4.11 Case Study 10 (ii): Instantaneous Design Engineering Progress Report

This case is drawn from the same organization and interview as Case Study 10 (i). In this case, an instantaneous assessment and reporting on the design engineering progress is discussed. The progress of design engineering is assessed through metrics related to transmittals and document management. A dashboard provides information regarding the following; overdue transmittals, top overdue transmittals, deliverable documents, rejected documents, and more. In addition to the quantifying progress, the system uses neural network algorithms to predict the completion time for the engineering documents.

This system allows for the easy identification of design bottlenecks and allows for better alignment between engineering and construction. In order for the system to be used effectively, it should be contractually required.

6.5 Instantaneous Controls Practices

Analysis of the case studies revealed that not one organization was found within the construction industry that controlled its projects in a completely instantaneous manner. However, many instances were found within and outside the construction industry where instantaneous control functions had been implemented in one or more facets of their projects. The objective of implementing instantaneous functions has been to increase efficiency, minimize costs, reduce risk, and ultimately compete globally.

After collectively analyzing the case studies, it became evident that certain trends exist and common strategies could be found for implementing instantaneous controls. In total, nine key constructs were found that if sequentially and proactively addressed can result in an improved instantaneous project controls capability. These nine strategies are grouped into three categories of organizational behavior, project controls, and technologies (see Table 50).

Table 50

Categories and Strategies for Instantaneous Project Control Implementation

Category	Strategies/Practices
1. Organizational Behavior	1.1 Culture
	1.2 Leadership
	1.3 Contracting
2. Project Controls	2.1 Work Planning
	2.2 Data Collection
	2.3 Reporting
3. Technologies	3.1 Information Integration
	3.2 Workflow Management
	3.3 Business Intelligence

These nine key constructs need to be proactively considered to achieve meaningful improved instantaneous control capability. These nine practices have direct application in the construction industry. The organization was the unit of analysis for nine out of the ten case studies; thus, the strategies developed are for implementing instantaneous controls for the organization, as opposed to a stand-alone project. A discussion of the key issues in each of the practices follows.

6.5.1 Culture

Organizations should create a culture of continuous improvement, especially a culture of project controls improvement. To do so, the organization needs to create transparency and a culture of accountability. Project controls should be an important project management function that is incorporated into the daily managerial activities of the organization.

Correct procedures and policies should be defined by the organization in order to establish a culture of accountable, responsible, and transparent controls. A focus on training personnel toward their specific responsibilities and behavior should be made. In order to incentivize employees to better themselves in their project controls effort, periodic evaluations, reviews, feedback, and recognition packages should be established. In order to ensure continued improvement is made regarding project controls, periodic internal audits should be made.

6.5.2 Leadership

Upper or senior management have a responsibility to provide the organization with a sustained vision toward instantaneous project controls practices. This vision should be clear and feasible in light of available resources. Establishing recognition programs will create transparency in requirements and additionally will incentivize and motivate personnel.

Management should support efforts to implement instantaneous functions and acknowledge temporal problems or issues in establishing such control functions. Management should commit needed resources and assets for the realization of enhanced instantaneous controls. Resource allocation should be proportionate to the scope and effort needed to implement a specific instantaneous controls functions. Resource allocation should be followed by clear goal setting and expectations. Formal reviews, feedback, and recognition should also be established for all levels of management.

6.5.3 Contracting

Stakeholder and personnel responsibilities, including data collection, reporting, and communication requirements, should be clearly defined and put in writing. Such written responsibilities should be contractually enforced. There is a need to contractually include the required code structures, work breakdown structure, and other metrics in order to align the stakeholders throughout the project.

The details of communication interfaces, reporting requirements, and data collection efforts should be included in the contracts for all stakeholders of the project, including the owner down to the subcontractor. Therefore, deliverables should be aligned across organizations, communication interfaces should be defined, and milestones should be established.

6.5.4 Work Planning

Work planning is an important aspect that should be recognized when trying to support timely, informed, and proactive decision-making processes. Work planning encompasses front-end planning, the definition of planning processes, and assessment of work planning.

Work planning is achieved through work packages; work packages are defined based on the size and complexity of the project and should be aligned with the data collection, analysis, and reporting requirements of the project control functions. Additionally, work packages need to be aligned with the project execution plan. The success of the project should be assessed against these work packages, and the interfaces between these work packages should be effectively managed.

The coding structure of the project should be carefully developed in order to satisfy the project objectives and effectively support all aspects of project controls. The coding structure should be aligned among all departments through effective communication. For instance, the cost coding structure should be aligned with accounting and financials. Work packaging should be promoted by project organizations in order to promote continuous feed of data and on-demand reporting.

6.5.5 Data Collection

The requirements for data collection should be defined in well-drafted instructions, procedures, checklists, and/or standards within the organization. The data collection requirements should be aligned with key project performance metrics. Not all data need to be collected instantaneously due to the resource intensive nature of such an endeavor; rather, the frequency of data collection should be specified according to the needs and project objectives.

A requirement for data collection is that the acquired data should be correct, clean, consistent, and complete. Accuracy of data is important when making decisions; thus, order of magnitude or estimates should be avoided as much as possible. In order to ensure consistent data is acquired, data validation and audits should be established.

Ideally, project controls data should be automatically and continuously collected with minimal human effort in a way that manual collection or re-entry of data is eliminated. To ensure accuracy of the collected data, it should be captured at source. It should be noted that remote technologies, such as wireless, mobile, or cloud solutions, will help in bypassing or eliminating paper-based data collection efforts.

6.5.6 Reporting

Reporting frequency for each project controls function should be prioritized; this prioritization may include real-time and continuous monitoring of specific control functions. Reports should be automatically generated with the right metrics and level of detail to satisfy the needs of the stakeholder being reported to. Reports should be available anywhere and remotely using mobile, remote, and wireless technologies. When prioritizing project control functions, consideration for the timelines and relevancy of data should be taken.

6.5.7 Information Integration

Seamless exchange of project control data and information within and across organization boundaries results in successful information integration. Inefficient flow of information should be recognized and issues resolved so that cost and schedule functions can be effectively controlled. Seamless flow of information should be facilitated by automatic data transfer. Manual and semi-manual transfer of data may introduce inefficiencies, error, and lag within the information exchange process.

Seamless information flow should not jeopardize confidentiality nor cause redundancy or raise security flags. Information integration should guarantee appropriate information access. Storing data in a central repository may enhance data sharing and access with combined authorization protocols. Inhibiting factors across organizational barriers should be identified and resolved.

6.5.8 Workflow Management

Project workflows should focus on communication and information management technologies. Such workflows ensure that compliance is met with audit requirements and regulations. Appropriate authority or privileges should be given when designing the workflow based on project needs and project nature.

Workflows should streamline project control and management processes through the use of appropriate mechanisms, such as warnings, reminders, and escalation rules. Workflows should be designed to accommodate up-to-date information and communication technologies. Workflows should enable instantaneous project controls and management. Communication and information technologies should enforce compliance with requirements, such as audits, regulations, and standards.

6.5.9 Business Intelligence

The construction sector produces and handles an enormous amount of data. Analyzing this overwhelming amount of data by project managers is an impractical endeavor. Business intelligence or automated data analytics can result in timely analysis of this data.

Advanced analytics allow critical project questions to be answered instantly and are set to support strategic project decisions. Business intelligence incorporates intelligence functions that automatically and instantaneously inform, alert, and trigger actions based on actual or potential events and issues.

6.6 Validation

The case studies conducted are based on contextual and real-world evidence. This real-world evidence and contextual data provides a strong validation for the case study analysis and the practices developed in this study. Furthermore, a validation mechanism was implemented to generalize the practices outlined previously. This mechanism is a workshop with subject-matter experts and implementation studies. The workshop tried to gather the perceptions and opinions from subject-matter experts with no prior knowledge of this research on the findings and strategies gained from the case studies. Also, three distinct efforts to implement a prioritized reporting capability were investigated. The three implementation studies show the different levels of success and how they can be explained by the insights and practices gained from this research study.

The following three sections discuss three implementation efforts for instantaneous controls. Each effort has varying levels of success. In studies A and B, the organizations sequentially implemented the practices, while study C focused on implementing advanced information technologies without first addressing organizational behavior and project controls categories. Implementation studies A and B were successful in implementing improved and more instantaneous control functions. Study C. which only focused on technology-centric efforts. failed in its instantaneous controls implementation. These three studies are presented in the following sections.

6.6.1 Implementation Study A—Consolidated Organizational Behavior

The first implementation study relates to an advanced and sophisticated contractor. This contractor implements a field controls measure of daily data collection and analysis, which allows almost instant corrective actions as necessary. The company leadership promoted this daily endeavor, and the organization's culture encouraged continuous improvement, which allows individuals to contribute to the vision. The organization hierarchy was horizontal; thus, middle and higher management also contributed to continuous improvement and to the vision. The organization had a sophisticated work coding system to enable communication between different control functions. Its contracting methods included shared incentives and integrated project delivery process, which ensured shared responsibilities and collaboration between stakeholders. Additionally, the contractor employed advanced technologies, such as RFID sensors, cameras, and laser scanners, to monitor work-in-place.

Since the contractor ensured a high level of maturity in terms of organizational behavior and project controls strategies as defined in this research study, it was well suited to adopt advanced information technologies. The contractor indicated the company was using a commercial project repository tool to integrate project information, including BIM information with estimating, construction, and control functions. For instance, quantity takeoffs were taken from BIM. Also, productivity rates were retrieved from historical data to estimate resource requirements, such as crew, material, and equipment.

6.6.2 Implementation Study B—A Sequential Adoption of Strategies

This implementation study pertains to an owner organization in the health care sector. This implementation study shows the strategies outlined in this research study and how they should be leveraged sequentially. For more than 20 years, a legacy system was used for managing projects. This system was effective at managing budgets and schedules but not with detailed management of the projects. For instance, all contracts were manually outlined, transactions were performed on paper, and data and reporting were mostly shared through manual processes.

To enhance their project management practices, the owner organization set out to find a new software vendor. Since the owner organization built 20% of its projects, the vendor needed to meet both the needs of an owner and general contractor. Finally, a software vendor was selected; this vendor had significant experience in proposing integration tools that require minimal support.

Once the vendor was selected, leadership at the owner company assembled an implementation team comprised of both field personnel and home office team members. The vendor, in collaboration with the core group of experts, spent most of its time developing and streamlining practices and processes. Also, project non-financial and financial functions were reengineered in that order. Then, advanced information tools were implemented to transmit information from these functions and processes.

Once the implementation was completed, a set of user acceptance tests were run and only minor issues were detected. Finally, training manuals were developed to accommodate the larger community at the owner organization to implement this new system. In order to maintain the system, roles and responsibilities were assigned.

6.6.3 Implementation Study C—Software Alone Was Not the Solution: Two Failed Efforts

A large oil and gas company was twice documented as expecting a commercial software tool alone to improve its project control reporting capability. Without surprise and due to bypassing the two categories of organizational behavior and project controls, both instances failed.

The company procured software vendor services for a cost management tool for its turnaround maintenance support with two major goals. First, it hoped to provide forward-looking metrics to enable proactive decision-making. Second, it wanted to find problem areas in a timely manner to effectively support planning and execution efforts. The company existing systems used semi-automated spreadsheets to support cost functions, but management's vision was to provide a cost solution across all units. The company focused only on acquiring and implementing a cost information integration tool without considering the processes to be supported by the tool nor any clear business case to design, capitalize, and lead such an implementation. The main plan of the company was to implement the system on one refinery and assess if it could be used on all its refineries.

The first pilot implementation commenced in the fall of one year, for a turnaround project that was starting in January of the next year. Since the three-month lead time was short, the team did not have enough time to validate the information tool. Also, the scope of testing was unclear, as it was not focused on simple cost functions but rather trying to uncover any potential issues. Additionally, the software vendor failed to generate timely reports and address urgent issues as they occurred. It was also found that the database and application servers were incorrectly sized, which needed more time and funding during the pilot study.

A second pilot implementation effort commenced the following fall. To test the vendor system, the team decided to implement it on a streamlined turnaround project in tandem with the old spreadsheet management system. After the evaluation, it was concluded that the software tool required more overhead and resources than the semi-manual spreadsheets. Also, it took more time to generate reports and higher labor costs for data entry than expected.

Due to the problems during the pilot implementation efforts, the company decided to postpone the final acquisition of the software vendor services. It was determined that more time is needed for the assessment of the software, an appropriate work code structure should be developed beforehand, and a clear scope of implementation work should also be determined.

CHAPTER 7: BENEFITS OF INSTANTANEOUS PROJECT CONTROLS

In this section, Survey 2 and statistical analysis of the CII Benchmarking and Metrics Database (BM&M) is discussed in relation to how they fulfill objective 3—quantifying the benefits of IPC—of this research project.

Survey 2 was intended to discover IPC elements, characteristics, and requirements. As is discussed in this chapter, this survey investigated barriers and benefits to the implementation of instantaneous project controls, functions that are being monitored and controlled instantaneously, and also the perceived benefits of IPC on cost, schedule, and quality across the four project phases of design, procurement, construction, and commissioning and startup. Analysis of the 37 subject-matter responses revealed that three of the top five barriers to IPC implementation related to information integration and automated analytics (See Table 60), specifically, these barriers were lack of information integration, lack of a standard data exchange protocol, and lack of automated data analytics. As indicated by the findings from multiple lines of inquiry in this research, the comparison with projects with a fully implemented instantaneous controls capability is not yet possible. Thus, information integration and automated analytics were taken as surrogates of instantaneous controls.

Incidentally, CII Benchmarking and Metrics survey version 11.0 had investigated the maturity of internal and external information integration as well as automated analytics within construction organizations. We utilized the useful portion (78 responses) of this retrospective benchmarking database to quantify the benefits of IPC on project performance. Furthermore, a second dataset from the BM&M database was retrieved from CII containing summary statistics of cost data for 284 completed projects and schedule data for 262 completed projects. This second dataset was used as a benchmark to compare those high maturity projects—in terms of information integration and automated analytics—within the first dataset of 78 projects.

7.1 Survey 2—Instantaneous Control Survey

In this section, Survey 2 design, respondent characteristics, and findings regarding barriers and catalysts to IPC are delineated.

7.1.1 Design

In order to quantify and/or define the benefit and investment costs for instantaneous project control (Research Objective 3) a second survey instrument was created and distributed with a specific intent to establish the value proposition of instantaneous controls capability. Respondents to Survey 2 included 37 subject-matter experts affiliated with 18 separate organizations who responded to questions related to barriers, benefits, project controls structures, or the existence of instantaneous control functions within the organization. Survey 2 focuses questions at the organization level. It was determined that data integration and data sharing are two critically important core factors necessary to achieve instantaneous project controls.

7.1.2 Data Collection

The survey respondents on average had 24 years of experience (Question 6) in the capital industry, of which 20 years pertained to project controls specifically. The organizations involved in the survey provide a range of services and are mostly active in the Industrial Industry sector (Table 51). The common contracting method was lump sum (Table 52), and the most common project delivery was design-bid-build and design-build (Table 53). Most projects were in the United States and Canada, although other geographic regions are also represented (Table 54).. Most projects had a total installed cost of $10 to $100 million (Table 55). The number of full-time employees controlling the project ranged from none to more than 20 (Table 56). Most projects reported that they have both a central and a local office for project control purposes (Table 57). More than 70% of respondents reported they have an instantaneous data collection (Table 58), while more than 60% have instantaneous reporting (Table 59). The instantaneous functions being reported were mostly in the construction phase followed by commissioning, procurement, and engineering in that order (Table 60). The survey questionnaire is presented in Appendix II.

Table 51

General Industry Sector (Question 8)

	Response Total
Heavy Industrial	28
Light Industrial	15
Buildings	9
Infrastructure	17
Other[a]	2

[a] Other sectors include oil & gas facilities & pipelines, and nuclear

Table 52

Project Contracting Methods (Question 14)

	Response Total
Lump Sum	31
Guaranteed Maximum Price (GMP)	12
Unit Price	9
Cost Plus Fixed Fee	11
Time and Materials	17
Other	2

Table 53

Project Delivery Methods (Question 15)

	Response Total
Design-Bid-Build	21
Design-Build (EPC)	25
CM at Risk	12
Parallel Primes	3
Other[a]	3

[a] Other Methods include engineering, procurement, construction management (EPCm); design-build-operate; and basic design & FEED

Table 54

Project Geographic Location (Question 18)

	Response Total
United States	37
Canada	11
Western Europe	6
Eastern Europe	4
Asia	9
Middle East	4
Central America	7
South America	6
Africa	5
Oceania	2

Table 55

Project Range of Installed Cost (Question 19)

	Response Total
Less than $1 million	12
$1 to $10 million	16
$10 to $100 million	25
$100 to $500 million	20
$500 million to $1 billion	6
$1 to $10 billion	6
More than $10 billion	3

Table 56

Number of Full-Time Employees that Control the Project (Question 20)

	Response Total
None or less than 1	2
1	2
2	5
3	5
4	2
5	6
6	0
7	0
8	1
9	0
10	1
11 to 15	4
16 to 20	3
21 or more	6

Table 57

Project Controls Office Structure (Question 21)

	Response Total
Central Project Controls Office	2
Local Project Controls Office	7
Both Central and Local Offices	26

Table 58

Any Functions with Instantaneous Data Collection? (Question 26)

	Response Total
Yes	24
No	9
Don’t Know	1

Table 59

Any Functions with Instantaneous Reporting? (Question 27)

	Response Total
Yes	22
No	10
Don't Know	3

Note. Nineteen respondents indicated that they have both instantaneous data collection and reporting. three respondents indicated instantaneous data collection but non-instantaneous reporting.

Table 60

Phases with Instantaneous Function (Question 29)

	Response Total
Engineering	4
Procurement	7
Construction	17
Commissioning and Startup	8

7.1.3 Barriers and Catalysts

With the aid of case studies and literature review, several barriers and benefits to IPC implementation were conceived in several research charrettes. The respondents to the survey were asked to choose the top five most critical items on these lists, in no particular order. It was determined that data integration and data sharing are two critically important core factors necessary to achieve instantaneous project controls.

Table 61 and Table 62 summarize the rank order of perceived barriers and benefits respectively to instantaneous controls by number industry practitioners' responses. The research revealed that information integration and automated analytics prevail in three of the most prominent barriers (barriers #1, #2, #5). This finding is consistent with the case study analyses on instantaneous control functions, which emphasize both the integration of data to seamlessly share data and information and the automation of data analysis processes as core competencies for near real-time controls as is discussed in detail in Chapter 6.

Table 61

Barriers to Instantaneous Project Controls (Question 47) (n=37)

Rank	Barrier	Responses
1	Lack of information integration (e.g., through a common information system or database)	22
2	Lack of a standard data exchange protocol (across information systems such as ERP, materials, procurement, etc.)	17
3	Delayed data acquisition and/or data input	15
4	Varying needs among different projects (e.g., project types, sizes, location, contract strategies, etc.)	15
5	Lack of automated data analytics (e.g., part or all information automatically analyzed without human intervention	11
6	Lack of a common cost coding structure (e.g., across estimating, design-engineering, and execution)	10
7	Resistance to change current project controls methods, manuals, or procedures	10
8	Different control requirements and needs among owner, contractor and regulatory agencies	10
9	Lack of project team support to facilitate the implementation of instantaneous project controls	8
10	Unclear return of investment (ROI) from instantaneous project controls	7
11	Inadequate project team experience and skills	6
12	Lack of project team alignment	6

Table 62 summarizes the benefits identified by subject matter experts for instantaneous project controls in rank order of importance or value.

Table 62

Project-Related Benefits of Instantaneous Project Controls (Question 48) (n=37)

Rank	Benefit	Responses
1	Reliable and timely decision-making by project managers	24
2	Improved schedule performance	17
3	Focus on critical project metrics	16
4	Improved cost performance	16
5	Shift towards analyzing information vs. collecting data	13
6	Risk Mitigation	12
7	Improved resource allocation	11
8	Improved scope control	11
9	Data integration and standardization	10
10	Consistent and timely data, with an implicit emphasis on data quality	9
11	Reliable and timely decision-making by corporate managers	6
12	Reliable and rapid validation of information through access to recently collected data	6

Additionally, the survey inquired about the potential impact of IPC implementation on cost, schedule, quality, and scope functions for each phase. The results of this inquiry are presented in Tables 63 to 66 and Figures 19 to 22. It is observed that the potential impact of IPC functions is weighted on the construction phase; in other words, it is perceived that IPC solutions are to have the greatest positive impact during the construction phase of the project. This is intuitively correct since the construction phase is where most of the value of the project lies and most activities occur.

Table 63

Potential Positive Impact on Cost Performance from IPC Functions (Question 49)

	No Positive Impact	Somewhat Positive Impact	Moderate Positive Impact	High Positive Impact	Extremely High Positive Impact
Design/Engineering	3	11	7	8	1
Procurement	3	6	12	9	1
Construction	1	0	7	14	8
Commissioning and Startup	1	5	12	11	1

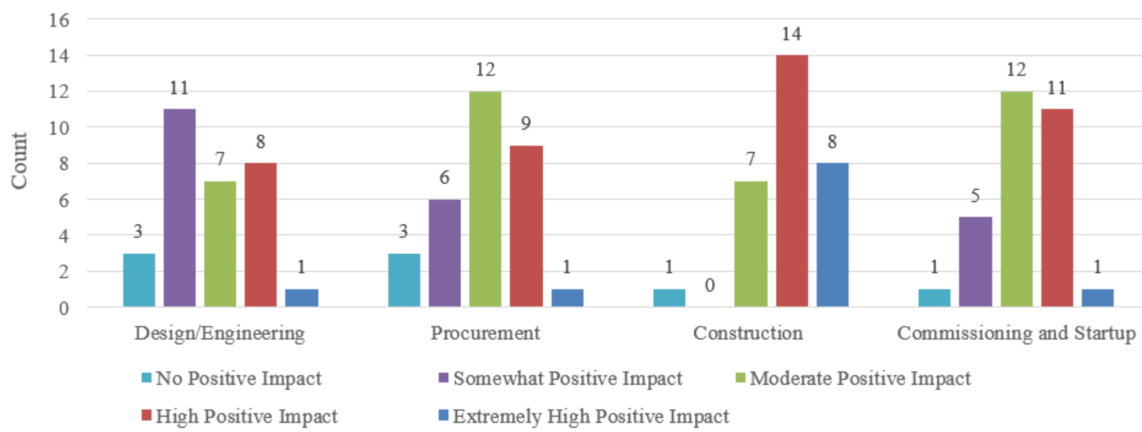


Figure 19. Potential Positive Impact on Cost Performance from IPC Functions (Question 49).

Table 64

Potential Positive Impact on Schedule Performance from IPC Functions (Question 50)

	No Positive Impact	Somewhat Positive Impact	Moderate Positive Impact	High Positive Impact	Extremely High Positive Impact
Design/Engineering	2	6	4	14	3
Procurement	2	7	5	14	2
Construction	1	0	5	13	10
Commissioning and Startup	1	2	6	15	4

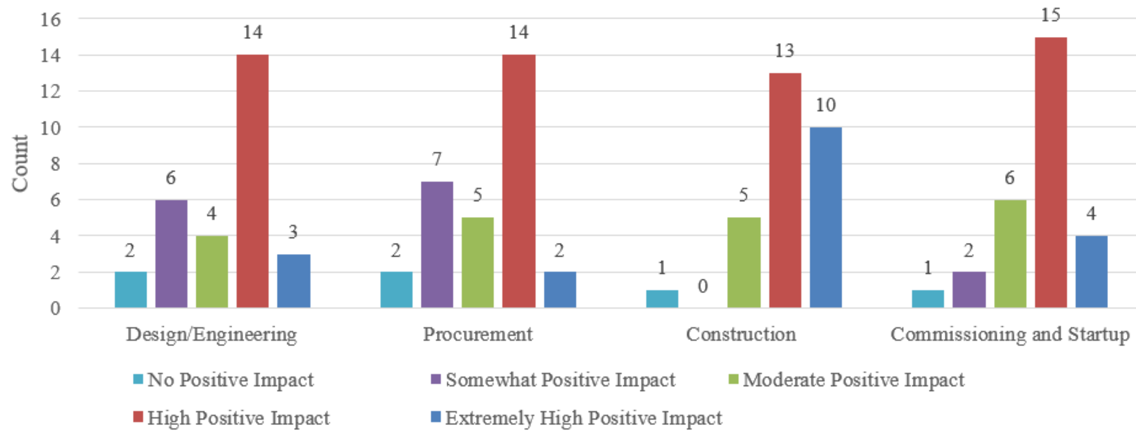


Figure 20. Potential Positive Impact on Schedule Performance from IPC Functions (Question 50).

Table 65

Potential Positive Impact on Quality Performance from IPC Functions (Question 51)

	No Positive Impact	Somewhat Positive Impact	Moderate Positive Impact	High Positive Impact	Extremely High Positive Impact
Design/Engineering	5	8	8	9	0
Procurement	7	5	10	6	1
Construction	2	4	6	14	3
Commissioning and Startup	5	2	10	10	1

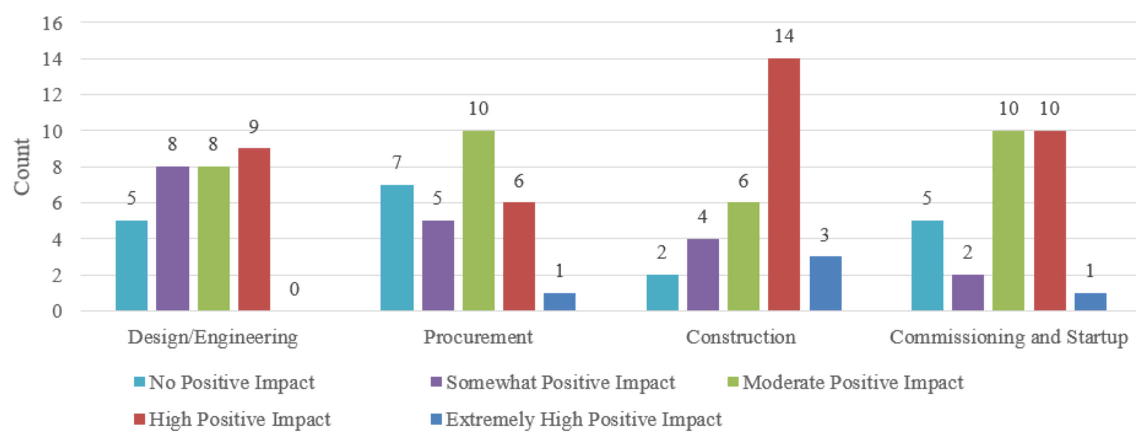


Figure 21. Potential Positive Impact on Quality Performance from IPC Functions (Question 51).

Table 66

Potential Positive Impact on Scope Performance from IPC Functions (Question 52)

	No Positive Impact	Somewhat Positive Impact	Moderate Positive Impact	High Positive Impact	Extremely High Positive Impact
Design/Engineering	2	7	6	12	4
Procurement	4	8	9	6	3
Construction	2	3	9	9	7
Commissioning and Startup	3	5	10	9	2

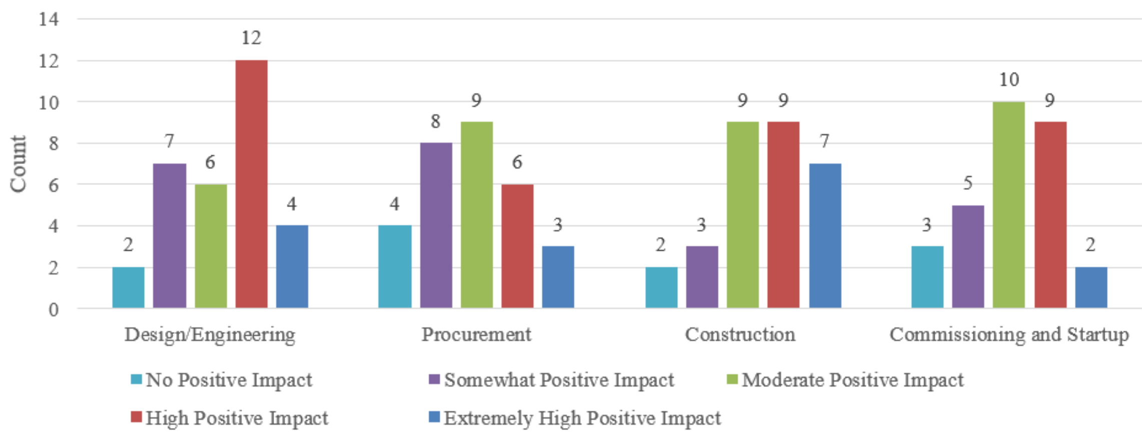


Figure 22. Potential Positive Impact on Scope Performance from IPC Functions (Question 52).

7.2 CII BM&M Questionnaire

CII BM&M database version 11.0 of completed projects characterizes, for each completed project and through a 5-point Likert scale, the maturity of internal and external information integration as well as automated data analytics. Thus, these two facets (information integration and automated data analytics) were used in this study as surrogates of real-time project controls.

The newly reported dataset pertains to a sample of 78 projects with a total installed cost of $8 billion, which was used for statistical analysis purposes. The projects were completed between 2008 and 2013. The CII project data represents both owner and contractor completed projects for U.S. domestic and international projects. Most projects in the sample were performed in the heavy and light industrial sectors (Table 67). The majority of the 78 projects had been delivered though DBB, DB (or EPC), and Parallel Primes. The top project business drivers were operability and production capacity. The project driver for half of the reported projects was both cost and schedule, while the driver for the other projects was either cost or schedule. In terms of contract types, the presence of cost reimbursable and lump sum contracts was prevalent across project phases. Most projects were defined as either grassroots or modernization nature. Other project characteristics can be viewed in Tables 68 to 78.

Table 67

Project Mix

Population Characteristic	Classes	Number of Projects	Percent of Projects
Company Type	Owner	60	77
	Contractor	18	23
Industry Sector	Heavy Industrial	37	47.3
	Light Industrial	15	19.2
	Building	19	24.5
	Infrastructure	7	9
Total Installed Cost	< $5 million	11	14.1
	$5-$15 million	9	11.5
	$15-$50 million	23	29.5
	$50-$100 million	10	12.8
	$100-$500 million	13	16.7
	> $500 million	6	7.7
Project Nature	Grassroots	23	29.5
	Brownfield	9	11.5
	Modernization	30	38.5
	Addition	15	19.2
	Other	1	1.3
Project Locations	Domestic (U.S.)	59	76
	International	19	24
Delivery Method	Traditional DBB	40	51.3
	Design Build	21	27
	Parallel Primes	11	14
	CM@Risk	5	6.4
	Other	1	1.3

Table 68

Projects' Distribution by Project Country (%)

United States	Canada	United Kingdom	Spain	Egypt	Italy	Belgium	China	Singapore
77	11.6	2.6	2.6	2.6	2.6	1.3	1.3	1.3

Table 69

Projects' Distribution by Project Industry Group (%)

Heavy Industrial	Light Industrial	Building	Infrastructure
47.4	19.2	24.6	9

Table 70

Projects' Distribution by Project Nature (%)

Grassroots	Brownfield	Modernization	Addition	Other
29.5	11.5	38.5	19.2	1.3

Table 71

Projects' Distribution by Project Business Driver (%)

Quality	Risk	Production Capacity	Operability	Environmental	Social	Other
18	23%	44.9	43.6	25.6	9	10.3

Table 72

Projects' Distribution by Project Priority (%)

Project Cost	Project Schedule	Project Balanced
21.8	28.2	50

Table 73

Projects' Distribution by Project Cost Category (%)

< $5M	$5M-$15M	$15M-$50M	$50M-$100M	$100M-$500M	> $500M
14.1	11.5	29.5	12.8	16.7	7.7

Table 74

Projects' Distribution by Project Delivery Method (%)

Traditional DBB	Design Build	Parallel Primes	CM@Risk	Other
51.3	27	14.1	6.4	1.3

Table 75

Contract Type for Engineering Design (%)

Cost Reimbursable	Lump Sum	Time Material	Cost Plus Fee
59	26.90	3.80	2.60

Table 76

Contract Type for Procurement (%)

Cost Reimbursable	Lump Sum	Time Material	Unit Price
44.90	34.60	3.80	2.60

Table 77

Contract Type for Construction (%)

Cost Reimbursable	Lump Sum	Cost Plus Fee	Time Material
43.60	35.90	12.80	2.60

Table 78

Contract Type for Commissioning and Startup (%)

Cost Reimbursable	Lump Sum	Time Materials	Cost Plus Fee
47.40	24.40	2.60	1.30

7.3 Automation and Integration Use Level

As mentioned earlier, the maturity of project internal and external information integration as well as automated analytics was rated based on a five-point Likert scale.

For each Likert scale point, a definition for the two facets was developed by CII, which can be viewed in Table 79 and Table 80. These definitions were used to collect self-rating scores for information integration and automated analytics levels.

Table 79

Automation Use Level Scores

Use Level	Description
None (1)	No electronic tools or commonly used electronic tools, all processes completed manually
Minimal (2)	Checklists or simple tools are available to help complete the process
Moderate (3)	Electronic tools are available to help complete part of the work
Extensive (4)	Electronic tools complete most of the work after entering input data, with minimal amount of manual work after data are entered
Complete (5)	Entire process automatically completed after input data are entered.

Table 80

Integration Use Level Scores

Use Level	Description
None (1)	*No data communication* or sharing with other electronic tools
Minimal (2)	Data (or information) produced from the work function are transferred manually because the data are *rarely interoperable.*
Moderate (3)	Data (or information) produced from the work function are still manually transferred but some data are *somewhat interoperable* with other functions/stakeholders.
Extensive (4)	Data (or information) produced from the work function are *mostly interoperable* with other functions/stakeholders and do not require manual transfer.
Complete (5)	Data (or information) produced from the work function are *seamlessly interoperable* with other functions/stakeholders and no manual data transfer is required.

7.4 Automation and Integration (A/I) Index

The previously defined use levels were used by the respondents to the BM&M Questionnaire to self assess their projects. To calculate automation and integration indices, the same scoring system as the use levels was used. Since each phase of the project was scored in terms of their Internal Integration (II), External Integration (EI), and Automation (AT) (Table 81), the project level integration and automation indices were calculated as simple arithmetic means of these phases and range from 1 to 5 using the formula below.

$$\text{Project level A/I index} = \frac{\text{Average phase level use score}}{\text{\# of phases reported}}$$

In each project within the BM&M database, automation and integration maturity assessments were defined at each phase of the project, while schedule and cost performance information were defined not only for each phase but also at project completion. A single index of technology maturity consistent with the levels of internal and external integration and automated analytics was defined as the Automation/Integration (A/I) index. For statistical comparison purposes, the sampled projects were grouped into high scoring of A/I index and low scoring A/I index. Projects with a high level of Automation/Integration were defined with a minimum score of 3.5 to 5, and projects with a low level of Automation/Integration had a maximum score of 2.5. Projects with intermediate scores between 2.5 and 3.5 were not considered so that the disparity between the two other groups could be evident.

Table 81

Phases Used to Measure the Degree of Information Integration and Automated Analytics Technology Use

Phase	Use level					NA/UNK
	1	2	3	4	5	
Engineering						
Construction						
Procurement						
Commissioning and Startup						

For the purposes of this study, automation and information integration are defined as below:

- Information integration is defined as an information tool that enables the seamless communication of data and information to the organization (internally) or/and to project stakeholders (externally).
- Automated data analytics is defined as the automation of the analysis of raw data in order to generate information.

7.5 IT Use

Tables 82 to 85 illustrate the use of IT for the BM&M database. These tables show the A/I index score corresponding with each percentile for each data type. We present the discussion of the results summarized in the tables. Larger projects (>$100 million) have reported higher A/I use levels than smaller projects. This finding is in line with previous studies that have shown that larger and more complex projects show greater use of technology. It is also observed that grassroots and brownfield projects show higher A/I use levels than that of modernization and additions projects. The distribution of A/I use across industry sectors reveals that generally top-ranking building projects (closely followed by heavy industrial projects) use higher degrees of A/I than infrastructure projects within this sample. Light industrial projects show the least amount of A/I use among the four industry sectors within this sample.

Table 82

Percentile Ranking of A/I Index Scores for Project Nature

Percentile Ranking	All Projects	Project Nature			
		Grassroots	Brownfield	Modernization	Addition
100	4.800	**4.800**	4.167	4.750	4.000
90	4.000	**4.333**	4.033	3.738	3.667
75	3.454	3.556	**3.833**	3.417	3.125
50	3.000	2.733	**3.000**	**3.000**	2.667
25	2.217	2.400	**2.667**	2.200	2.267
10	2.000	2.000	**2.333**	2.133	1.917
0	1.067	2.000	**2.333**	1.733	1.067
Mean	2.916	3.007	**3.178**	2.881	2.698
Std. dev.	0.768	0.822	0.653	0.715	0.786
n	70	21	9	28	9

Note. Boldface indicates best performance within category

Table 83

Percentile Ranking of A/I Index Scores for Industry Sector

		Industry Sector			
Percentile Ranking	All Projects	Heavy Industrial	Light Industrial	Building	Infrastructure
100	4.800	4.750	3.733	**4.800**	3.833
90	4.000	4.000	3.373	**4.233**	3.767
75	3.454	3.417	3.000	3.589	**3.667**
50	3.000	3.000	2.833	3.000	**3.250**
25	2.217	2.200	2.283	**2.425**	2.200
10	2.000	**2.133**	2.097	2.000	1.920
0	1.067	**2.000**	1.067	1.917	1.733
Mean	2.916	2.945	2.673	**3.076**	2.937
Std. dev.	0.768	0.736	0.647	0.876	0.828
n	70	37	14	14	5

Note. Boldface indicates best performance within category

Table 84

Percentile Ranking of A/I Index Scores for Cost Category

		Cost Category		
Percentile Ranking	All Projects	< $15 m	$15-$100 m	> $100 m
100	4.800	4.000	4.444	**4.750**
90	4.000	3.687	3.758	**4.133**
75	3.454	3.413	3.379	**3.667**
50	3.000	2.233	**3.000**	**3.000**
25	2.217	2.200	2.425	**2.667**
10	2.000	2.093	2.000	**2.333**
0	1.067	**2.000**	1.067	**2.000**
Mean	2.916	2.738	2.916	**3.151**
Std. dev.	0.768	0.689	0.715	0.754
n	70	18	30	17

Note. Boldface indicates best performance within category

Table 85

Percentile Ranking of A/I Index Scores by Project Phase

		Project Phase				
Percentile Ranking	All Projects	FEP	Design	Procurement	Construction	Commissioning
100	4.800	**5.000**	**5.000**	**5.000**	**5.000**	4.333
90	4.000	**4.000**	**4.000**	**4.000**	**4.000**	**4.000**
75	3.454	3.333	**3.917**	3.667	3.000	3.333
50	3.000	2.667	**3.000**	**3.000**	**3.000**	**3.000**
25	2.217	2.000	2.333	**2.667**	**2.667**	2.000
10	2.000	1.667	2.000	**2.233**	2.000	1.333
0	1.067	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
Mean	2.916	2.711	**3.081**	3.078	2.913	2.748
Std. dev.	0.768	0.915	0.831	0.821	0.777	0.929
n	70	60	66	58	61	49

Note. Boldface indicates best performance within category

7.6 Impact of Information Integration and Automated Analytics on Project Performance Outcomes

This section presents the relationship between project categories, quartiles, automation, and integration with project cost and schedule outcomes. The following project performance metrics are used to measure project outcome:

$$\text{Project cost growth} = \frac{\text{Actual project cost - Baseline cost}}{\text{Baseline cost}}$$

Delta project cost growth = | Project cost growth | (Kang et al., 2008)

$$\text{Project schedule growth} = \frac{\text{Actual project schedule - Baseline schedule}}{\text{Baseline schedule}}$$

Delta project schedule growth = | Project schedule growth | (Kang et al., 2008)

Project cost and schedule growth indicate overrun and underrun of project performance outcome. Smaller values indicate better performance. While Delta project cost and schedule growth indicate the predictability of baseline estimates, closer values to zero indicate better outcome predictability. Extreme outliers were defined as any value 3.5 times standard deviation away from the median and were eliminated to reduce bias in results.

To better understand the dataset, project performance outcomes are presented based on categories (Tables 86 to 88). It is observed that as projects become larger (in terms of installed cost) cost and schedule growth as well as delta project schedule growth become worse, while delta project cost growth demonstrates better performance. Looking at project performance by project nature reveals modernization projects having the best project cost and schedule growth performance as well as best schedule predictability. On the other hand, addition projects demonstrate better cost predictability performance. Looking at project performance by industry sector reveals that infrastructure projects perform best in terms of project cost growth, but since the number of data points for infrastructure projects is small (n=5), by disregarding these projects light industrial projects demonstrate overall superior cost and schedule performance in terms of growth and predictability.

Table 86

Mean Project Performance Outcomes by Project Nature

		Project Nature			
Performance Metric	All Projects	Grass	Brown	Modern	Add.
Cost					
Project cost growth	-3.8%	3.4%	-9.1%	**-11.2%**	-4.3%
Delta project cost growth	17.6%	17.5%	26.7%	15.6%	**10.5%**
Schedule					
Project schedule growth	7.3%	13.2%	21.6%	**-0.9%**	7.7%
Delta project schedule growth	15.4%	18.6%	33.3%	**8.9%**	14.4%

Note. Boldface indicates best performance within category

Table 87

Mean Project Performance Outcomes by Industry Sector

		Industry Sector			
Performance Metric	All Projects	Heavy Industrial	Light Industrial	Building	Infrastructure
Cost					
Project cost growth	-3.8%	-2.7%	-4.6%	-1.9%	**-16.2%**
Delta project cost growth	17.6%	22.1%	**10.9%**	13.7%	16.2%
Schedule					
Project schedule growth	7.3%	7.7%	**4.6%**	7.0%	17.1%
Delta project schedule growth	15.4%	19.0%	**8.5%**	11.9%	25.5%

Note. Boldface indicates best performance within category

Table 88

Mean Project Performance Outcomes by Cost Category

		Cost Category		
Performance Metric	All Projects	< $15 m	$15-$100 m	> $100 m
Cost				
Project cost growth	-3.8%	**-9.2%**	-6.2%	7.1%
Delta project cost growth	17.6%	20.3%	18.9%	**11.7%**
Schedule				
Project schedule growth	7.3%	**-1.6%**	7.8%	15.3%
Delta project schedule growth	15.4%	**13.1%**	14.4%	20.6%

Note. Boldface indicates best performance within category

In Table 89 and Table 90, project performance outcomes are categorized based on A/I index scores to better understand the correlation between the two. The first quartile A/I index scores represent those projects with the highest automation and integration maturity and the second, third, and fourth quartiles are lower maturity projects in that order. It is observed that higher IT use, interconnected information systems, and automated analytics result in better project cost and schedule growth performance for all projects and owner projects. Looking at schedule growth for all projects and contractor projects, it is consistently seen that moving from the forth quartile (lowest use of automation/integration systems) to the first quartile improves these metrics. For some cases a performance penalty is observed when moving from the fourth quartile to the third quartile (for instance, cost growth for all projects). This may be due to a learning curve penalty—such performance penalty has been reported in Thomas (1999), Thomas et al. (2001), and to a lesser extent in Kang et al. (2008). For cost predictability, the third quartile illustrates best performance, and for schedule predictability, the second quartile is showing best performance, which is not what was expected. A one-way ANOVA hypothesis test was conducted to assess if the project performance outcome means between the four quartiles were statistically different. The result of the ANOVA test did not reveal any statistical difference between the four groups.

Table 89

A/I Index Scores Correlation with Mean Project Performance—Owners and Contractors

Performance metrics		A/I index scores				
		Low maturity		High maturity		
	n	4th quartile	3rd quartile	2nd quartile	1st quartile	No use to greatest benefit
Cost						
Project cost growth	63	-3.2%	*-2.4%*	-4.0%	**-5.4%**	2.1%
Delta project cost growth	63	*23.0%*	15.7%	**11.6%**	22.7%	11.4%
Schedule						
Project schedule growth	58	*13.7%*	8.2%	7.9%	**3.1%**	10.6%
Delta project schedule growth	58	**14.1%**	15.2%	*19.3%*	15.6%	—

Note. Boldface indicates best performance within category. Italics indicate worst performance within category.

Table 90

A/I index Scores Correlation with Mean Project Performance—Owners

Performance metrics	n	A/I index scores: Low maturity		A/I index scores: High maturity		No use to greatest benefit
		4th quartile	3rd quartile	2nd quartile	1st quartile	
Cost						
Project cost growth	46	*4.0%*	1.3%	-8.4%	**-12.0%**	16.0%
Delta project cost growth	46	*23.3%*	21.9%	**9.7%**	21.5%	13.6%
Schedule						
Project schedule growth	42	6.6%	*16.3%*	3.3%	**0.0%**	6.6%
Delta project schedule growth	42	**10.0%**	*22.7%*	17.8%	16.4%	—

Note. Boldface indicates best performance within category. Italics indicate worst performance within category.

The parametric two-tailed t-test and non-parametric Mann-Whitney test at the α=0.05 level was performed in order to determine the significance of the cost and schedule performance difference projects with high and low level of technology maturity. Although the results were not statistically significant, such results indicate that the seamless communication of information and the ability to generate automated, and hence on-demand, reports can eventually result in large impacts on cost and schedule performance. The results (see Table 91) show that, on average, integration and automation technologies result in improved cost and schedule performances. For instance, higher levels of information integration and automated analytics improve project cost performance at completion by 3.34%. Also, the reader should notice that there is a stronger positive relationship between integration and automation practices and schedule performance than cost performance; this has been consistently shown in previous studies (El-Mashaleh et al., 2006; Kang et al., 2008; O'Connor & Yang, 2004).

Table 91

Impact of Information Integration and Automated Analytics on Project Performance

Project Type	Cost		Schedule	
	Count (low, high)	Average Performance Impact	Count (low, high)	Average Performance Impact
All	21,14	-3.34%	19,15	-5.31%
Grassroots and Brownfield	7,7	-6.53%	8,8	-15.80%

By observing project II, EI, and AT scores, it was found that projects with higher levels of internal integration had better inter-organizational or external integration. It was also observed that projects with mature integration processes scored high in terms of automated analytics.

7.7 Impact of Information Integration and Automated Analytics on Construction Performance Outcome

Table 92 below shows the distribution of project cost across the four project phases of engineering, construction, procurement, and commissioning and startup. It is evident that construction and procurement phases comprise most of the project cost (>90%). The construction phase was isolated to investigate the effect of technology use on project performance outcome (see Table 93).

Table 92

Distribution of Project Cost Across Phases

Phase	Percent of Overall Cost
Engineering	6.50%
Procurement	39.24%
Construction	51.34%
Commissioning and Startup	2.93%

Table 93

Impact of Information Integration and Automated Analytics on Construction Performance

	t-test for equality of means					
Metric	t	Degree of Freedom	Significance (two-tailed)	Mean Impact	Std. Error Difference	95% confidence interval
Cost growth						
Automation	2.411	24	**0.024**	-20.36%	0.08443	0.297~0.378
Internal Integration	2.317	11	**0.040**	-23.08%	0.09964	0.126~0.449
External Integration	0.147	25	0.884	-1.22%	0.08289	-0.158~0.183
Composite						
Integration index	-0.115	21	0.91	1.12%	0.09762	-0.214~0.191
A/I index	0.845	16	0.41	-8.49%	0.10042	-0.127~0.297
Schedule growth						
Automation	1.791	27	0.096	-21.06%	0.12202	-0.039~0.460
Internal Integration	2.187	20	**0.040**	-30.20%	0.13806	0.147~0.589
External Integration	0.996	23	0.329	-12.48%	0.12525	-0.134~0.383
Composite						
Integration index	0.656	27	0.517	-9.80%	0.14939	-0.208~0.404
A/I index	0.741	22	0.467	-10.92%	0.1475	-0.196~0.415

7.8 Benchmarking of Mature Projects in Terms of Information Integration and Automated Analytics

Since the datasets in the CII BM&M version 11.0 was rather small (78 projects), we retrieved performance summaries for more than 250 completed projects from 2007 to 2015 to use as benchmarks to compare with high-scoring A/I index projects. The results are in Table 94 and Table 95 and show that high technology use projects perform 5.4% better in terms of cost performance and 5.63% in terms of schedule performance than benchmark projects. A two-tailed t-test at the $\alpha = 0.05$ level was performed on the summary statistics to determine if these differences were statistically significant. The results of the hypothesis test did not show any statistical significance.

Table 94

Benchmark Projects Versus Projects with a High A/I Index—Cost Performance

All projects		High A/I index projects		Impact on Cost
Count	Mean Cost Deviation	Count	Mean Cost Performance	
284	-0.26%	14	-5.66%	-5.40%

Table 95

Benchmark Projects Versus Projects with a High A/I Index—Schedule Performance

All projects		High A/I index projects		Impact on Schedule
Count	Mean Schedule Deviation	Count	Mean Schedule Deviation	
262	12.40%	15	6.77%	-5.63%

7.9 IT Use Over Time

To assess the growth of IT use over time, data from three previous studies was used (Kang et al., 2008; Thomas, 1999; Thomas et al., 2001). The first data set pertains to reported projects in 1997 and 1998 (Thomas, 1999), the second study contains data collected between 1997 and 1999 (Thomas et al., 2001), and the third study covers data collected between 2002 and 2004 (Kang et al., 2008). Thomas (1999) and Thomas et al. (2001) use four specific technologies, namely 3D CAD, Electronic Data Interchange (EDI), barcoding, and integrated databases, and scored to comprise the Design and Information Technologies (D/IT) score. The study by Kang et al. (2008) pulls data from a different CII BM&M database where 13 work functions are scored based on their automation and integration use levels, an Automation/Integration tech score is then computed from these underlying work functions. The scoring scale for these three studies ranges from zero to 10 with zero being the least and 10 the most technology use. The A/I index in this study was modified using the formula below to make the scores across the studies somewhat consistent.

$$\text{A/I index (modified)} = \frac{\text{A/I index-1}}{4} \times 10$$

The scores from these studies are not directly comparable due to the underlying scoring system used. However, it can be observed that for owners 25% of respondents to the studies by Thomas (1999) and Thomas et al. (2001) did not use any level of technology while only one project out of 130 reported projects by Kang et al. (2008) reported no technology use, and in the current study all projects reported some degree of technology use. It is further observed that the standard deviations across the studies are somewhat consistent for both owners and contractors alike. Comparing scores for each percentile, previous studies indicate higher scores for contractors. The interpretation of contractor results for our study should be made with caution due to the limited number of projects (n=18), but findings from this study suggest higher scores for owners.

Table 96

IT Use Over Time—Owners

	D/IT score		A/I tech score	A/I index
Percentile Ranking	Thomas 1999	Thomas et al. 2001	Kang et al. 2008	Abbaszadegan 2016
Years data collected	1997-1998	1997-1999	2002-2004	2008-2013
100	7.88	9.38	9.688	9.500
90	3.64	4.00	7.183	7.063
75	1.79	2.15	6.010	6.073
50	0.75	0.86	4.050	5.000
25	0.00	0.00	3.368	3.292
10	0.00	0.00	2.558	2.683
0	0.00	0.00	0	0.167
Mean	1.28	1.45	4.638	4.818
Standard Deviation	1.59	1.76	1.930	1.878
n	183	316	94	52

Table 97

IT Use with Time—Contractors

	D/IT score		A/I tech score	A/I index
Percentile Ranking	Thomas 1999	Thomas et al. 2001	Kang et al. 2008	Abbaszadegan 2016
Years data collected	1997-1998	1997-1999	2002-2004	2008-2013
100	8.23	9.85	10	8.611
90	4.94	5.06	8.964	7.750
75	2.88	3.43	6.547	6.250
50	1.48	1.63	5.481	4.097
25	0.56	0.66	4.322	3.000
10	0.00	0.00	3.542	2.500
0	0.00	0.00	1.094	2.500
Mean	2.01	2.19	5.596	4.719
Standard Deviation	1.99	2.02	2.016	2.091
n	114	201	43	18

7.10 Discussion of Results

The purpose of this study was to identify real-time project controls implementation factors and assess the benefits of technology usage on project performance outcomes. Descriptive statistics were developed to determine technology usage across project categories. Additionally, hypothesis testing was performed to identify statistically significant relationships between technology usage and project-level and phase-level project performance outcomes.

This study identified barriers to real-time project controls implementation and assessed the impact of information aspects related to internal and external information integration and to automated analytics on the final performance of capital projects.

Initially, potential barriers to the implementation of real-time project controls were identified through an industry-wide survey of 37 respondents. The results showed that information integration and automated analytics were part of the top five barriers to real-time project controls implementation; as such, they were used as surrogates to real-time project controls. Incidentally CII BM&M survey version 11.0 had quantified these two metrics—automation and integration—thus, two datasets were drawn from CII BM&M databases, one with 78 projects (newly reported in this study) and another with more than 250 reported projects. Even though the results were not statistically significant, it seems clear that such positive impact can be realized.

Specifically, it was found that when comparing low-use with high-use technology project improvements of 3.34% in cost and 5.31% on schedule is achieved. These numbers are even more prominent when analyzing grassroots and brownfield projects only, with improvements of 6.53% in cost performance and 15.80% in schedule performance observed. Furthermore, after assessing high technology use projects against industry standards, it is revealed that such projects perform 5.40% better in terms of cost growth and 5.63% better in terms of schedule growth performance. Although IT use has a positive impact on cost and schedule performance, from findings in this study and studies by others, it is broadly found that IT use has a higher impact on schedule outcome than on cost performance.

A comparative study of IT score percentiles across several studies reveals that IT use is now more pervasive than 15 years ago. Contrary to previous studies, this study indicates a higher use of technology for owners than contractors.

Currently, a gap in the reporting cycle exists so that decisions are made on outdated information. Future research efforts should further investigate the impact of information integration and automated analytics by project phase. Future research should also focus on trends when moving from no technology use to a fully automated and integrated information system. This was partially shown in the quartile analysis (Table 96 & Table 97), but a larger data set is needed with specific case studies to understand trends and root cause for possible learning curve penalties. It will be beneficial to identify projects with high levels of A/I index and conduct case studies regarding technology use by such organizations. We did not have the luxury to do this due to confidentiality of CII BM&M data.

CHAPTER 8: INTELLECTUAL MERIT AND IMPACT

Through a mixed methods study approach with qualitative and quantitative aspects, a framework to answer the research objectives was developed that ultimately provided the following contributions to the AEC industry.

1. *Explored project controls from a comprehensive and holistic perspective:* Prior research has been sparse and has mainly focused on scheduling and costing of capital projects without the consideration of the various processes and functions related to controls.

2. *Current state of knowledge pertaining to project controls for the construction industry:* This study investigated current practices of project controls in terms of batch mode and state-of-the-art instantaneous practices. Among several findings, the frequency of data collection and reporting was measured for various project control functions; the pervasiveness of information technology utilization and integration of information systems was investigated.

3. *Development of an instantaneous project controls practices guideline:* The focus of previous studies were on cost and scheduling techniques alone but not practices for the implementation of instantaneous controls. They did not consider organizational processes and only focused on tools, techniques, and algorithms. For instance, there is a need to have the right data in a timely manner in order for the developed algorithms to be effective. Thus, a need for a holistic approach to monitoring and controls was identified with multiple perspectives drawn from the capital project industry and other industries. The developed framework can be generalized in any construction industry. Through a qualitative exploratory multiple case study within and beyond the construction domain, a

set of high-impact strategies or key constructs were identified. By studying specific organizations in several distinctly different industries, we identified functions that are being controlled in real-time and are considered as state-of-the-art project control functions. Upper managers were interviewed. Various industries were the focus of the case studies, but a manufacturing organization provided the greatest insights to this study. As a result of the case studies, nine key constructs were developed under the guise of three distinct categories of organizational behavior, project controls, and technologies.

4. *Distinction between monitoring and controlling:* Analyzing and reporting all control functions in real-time can be time-consuming and expensive. Thus, some functions can be monitored in real-time, while others are controlled based on a predefined frequency. As indicated by the case studies, quality is an example of a function monitored in real-time.

5. *Plausible potential benefits from implementation of instantaneous project controls on project performance:* The findings from Survey 2 presented the importance of advanced sensing and automation technologies for instantaneous support. Survey 2 allowed for the utilization of the CII BM&M database for quantification of real-time project control benefits. Retrospective data from the CII BM&M database regarding the maturity of project information integration and automated analytics along with data on the respective projects cost and schedule performance allowed for a cross comparison of highly mature projects and low mature projects in those two facets. By better understanding the benefits resulting from such real-time practices, management will be more willing to invest and focus on the strategies identified in this study.

CHAPTER 9: CONCLUSIONS

Several findings are reported in this research study, including a comprehensive definition of the existing condition within the construction engineering industry, an identification of barriers and benefits associated with the implementation of instantaneous project controls practices, detailed strategies and practices for the implementation of instantaneous controls capability, and finally the quantification of benefits from implementation of instantaneous controls. The findings represent grassroots, brownfield, modernization, and addition types of projects and the organizations involved with such projects.

Current project control practices are non-standard and fail to give the project authority timely and clear insight into the status of their projects. Current project controls processes are best described as a "batch" mode of controls where important project controls information is not available in real-time after the raw data has been collected. The industry believes that such batch mode of controls is not sufficient in meeting today's competitive needs and should be elevated to an instantaneous mode, or at least timely availability of information.

Several barriers were identified that must be overcome to achieve the goal of instantaneous controls. Overcoming barriers to instantaneous project controls can have positive benefits of different aspects of project control activities, including cost, schedule, quality, and scope. The research addressed how project controls data is collected, accessed, and utilized and presented how planning, monitoring, and controlling can be enhanced to support timely and accurate project controls reporting capability.

The research developed and presented practices and high-impact strategies for the facilitation of instantaneous project controls. These strategies address both the origination (“feed”) and accessibility (“read”) of project controls information so that real-time, or at least timely, capability is provided. Practical practices are presented and categorized as organizational characteristics of culture, leadership, contracting, work planning, data collection, documentation and reporting, information integration, workflow management, and business intelligence. In order to prioritize the implementation of instantaneous controls, two principles were defined. The first principle states that organizations should prioritize communication and reporting of project information by establishing specific reporting frequencies for each reporting function and organizational hierarchy (e.g., layer). This first principle implies that not all control functions require instantaneous or real-time reporting. For instance, while operating processes can be monitored in real-time, business and project metrics should be reported at prioritized and specific frequencies. The second principle states that highly variable functions that can significantly affect project performance should be instantaneously monitored. Events and issues causing disruption to the workflow or variations to the quality of work should be addressed immediately on the spot. The fundamental idea is that monitoring and reporting functions are to support timely and informed decisions and prevent negative impacts from late and uninformed decisions.

The monitoring and controls approach practiced by the manufacturing industry is slowly but steadily being adopted by construction industry organizations. As observed during the study, monitoring of quality, craft labor productivity, and scope functions indicate a shift toward instant monitoring and prioritized controls by construction industry organizations. Capital projects are actually highly variable processes; if this inherent variability is not addressed proactively, significant negative impacts can compound.

It is concluded that with the right set of practices instantaneous project controls is achievable. A comprehensive approach is needed, which starts with the definition of the reporting frequency as pertains to different layers of management. This research study contains universal findings applicable across business sectors within the construction engineering industry.

9.1 Future Studies

The research study herein utilized several modes and methods of inquiry so that the results would be meaningful across the industry, but there are several limitations that can be a basis for future studies.

Surveys are a powerful tool to construct trends within a large group, but the majority of projects in this research study pertained to industrial projects. A more balanced pool of projects will result in more realistic trends within the industry as a whole. This fact applies to the two surveys conducted and the two BM&M datasets utilized. The wide scope of the research poses limitations and benefits alike. The limitation is the available research time during the course of a PhD program. On the other hand, the benefit is the identification of a broad framework for implementation guidelines and the industry-wide study of project controls.

Additional future research should focus on documenting and quantitatively assessing the impact of instantaneous controls on project performance. Also, further studies should investigate the practices needed to satisfy control requirements for different project scenarios, such as size of projects (e.g., small vs. large), industry sector (e.g., industrial, buildings, infrastructure, etc.), and contracting methods (e.g., design-bid-build, design-build, integrated project delivery, etc.). Resource requirements such as time, cost, technology needs, and manpower for instantaneous controls can be investigated. And finally, specific data collection, information integration, and automated analytics aspects need to be explored in order to facilitate the implementation of instantaneous controls functions.

9.2 Contributors

Construction Industry Institute Research Team 316 was a contributor in this research study by providing several resources, including their expertise, connections regarding case studies, survey designs, CII BM&M database access, and others. I would like to specifically thank the following people for their contributions: Douglas Weaver (Chair), Robert Lobron (Vice Chair), David Grau (Principal Investigator), W. Edward Back (Principal Investigator), Lillie Alston, Mitchell Cornelius, Graciela Garcia de D'Uva, Rodolfo Gonzalez, Sandra Greene, Jeff L. Hoffa, Brian Kong, Brian R. Lipko, Chris Marcon, Patricia Pipping, and Stephen R. Thomas.

REFERENCES

Abudayyeh, O. Y., & Rasdorf, W. J. (1993). Prototype integrated cost and schedule control system. *Journal of Computing in Civil Engineering, 7,* 181–198.

Abudayyeh, O., Temel, B., Al-Tabtabai, H., & Hurley, B. (2001). An intranet-based cost control system. *Advances in Engineering Software, 32*(2), 87–94.

Ahmad, I., Azhar, S., & Lukauskis, P. (2004). Development of a decision support system using data warehousing to assist builders/developers in site selection. *Automation in Construction, 13,* 525–542.

Ahuja, V., & Thiruvengadam, V. (2004). Project scheduling and monitoring: Current research status. *Construction Innovation, 4,* 19–31.

Akinci B., Boukamp F., Gordon C., Huber D., Lyons C., & Park K. (2006). A formalism for utilization of sensor systems and integrated project models for active construction quality control. *Automation in Construction, 15,* 124–138.

Al-Jibouri, S. H. (2003). Monitoring systems and their effectiveness for project cost control in construction. *International Journal of Project Management, 21*, 145–54.

An, M., Baker, C., & Zeng, J. (2005). A fuzzy-logic-based approach to qualitative risk modeling in the construction process. *World Journal of Engineering, 2,* 1–12.

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

Assaf, S. A., Al-Khalil, M., & Al-Hazmi, M. (1995). Causes of delay in large building construction projects. *Journal of Management in Engineering*, *11*(2), 45–50.

Auerbach, C. F., & Silverstein, L. B. (2003). *Qualitative Data, An Introduction to Coding and Analysis*. Location: New York University Press.

Back, W. E., Boles, W. W., & Fry, G. T. (2000). Defining triangular probability distributions from historical cost data. *Journal of Construction Engineering and Management*, *126,* 29–37.

Back, W. E., & Grau, D. (2013a) Improving the Accuracy and Timeliness of Project Outcome Predictions. CII Research Summary 291-1.

Back, W. E., & Grau, D. (2013b). Four-casting for early predictability. Implementation Resource 291-2, Construction Industry Institute, Austin, TX.

Back, W. E., & Bell, L. C. (1994). Quantifying benefits attributable to electronic technologies. *AACE International Transactions*, SI1-1.

Back, W. E., & Moreau, K. A. (2000). Cost and schedule impacts of information management on EPC process. *Journal of Management in Engineering, 16*(2), 59–70.

Back, W. E., Moreau, K. A., & Toon, J. (1996). Determining the impact of information management on project schedule and cost. Research Report 125-11. Construction Industry Institute (CII), Austin, Texas.

Ballard, G., (2000). The last planner system of production control. (Doctoral dissertation). University of Birmingham.

Ballard, G. (1997, July). Lookahead planning: The missing link in production control. In *Proceedings of the 5th Annual Conference International Group for Lean Construction*, G*riffith University*, *Gold Coast*, *Australia*, *July*.

Ballard, G., Kim, Y. W., Jang, J. W., & Liu, M. (2007). Roadmap for lean implementation at the project level. *The Construction Industry Institute Research Report 243-11, Austin, Texas*.

Barraza, G. A., Back, W. E., & Mata, F. (2004). Probabilistic forecasting of project performance using stochastic S curves. *Journal of Construction Engineering and Management, 130,* 25–32.

Baum, J., & Wally, S. (2003). Strategic decision speed and firm performance. *Strategic Management Journal, 24,* 1107–1129.

Bourgeois III, L. J., & Eisenhardt, K. M. (1988). Strategic decision processes in high velocity environments: Four cases in the microcomputer industry. *Management Science, 34,* 816–835.

Bosche F., Teizer J., Haas C. T., & Caldas C. H. (2006). Integrating data from 3D CAD and 3D cameras for realtime modelling. *Joint International Conference on Computing and Decision Making in Civil and Building Engineering*, Montréal, Canada.

Burati, J. L. J., Farrington, J. J., & Ledbetter, W. B., (1992). Causes of quality deviations in design and construction. *Journal of Construction Engineering and Management, 118,* 34–49.

Callahan, M. T., Bramble, B. B., & Lurie, P. M. (1990). *Arbitration of construction disputes*. Location: Wiley Law Publications.

Callahan, K. R., Stetz, G. S, & Brooks, L. M. (2007). *Budgeting, tracking, and reporting costs and profitability* (2nd ed.). Hoboken, NJ: Wiley.

Chan, D. W., & Kumaraswamy, M. M. (1997). A comparative study of causes of time overruns in Hong Kong construction projects. *International Journal of Project Management*, *15*, 55–63.

Chan, S. L., & Leung, N. N. (2004). Prototype web-based construction project management system. *Journal of Construction Engineering and Management, 130,* 935–943.

Chau, K. W., Cao, Y., Anson, M., & Zhang, J. (2003). Application of data warehouse and decision support system in construction management. *Automation in Construction*, *12*, 213–224.

Cheung, S. O., Suen, H. C. H., & Chueng, K. K. W. (2004). PPMS: A web-based construction project performance monitoring system. *Automation in Construction, 13,* 361–376.

Chou, J. S., & Chong, W. K. (2008) A web-based framework of project performance and control system. *Proc., 2008 IEEE International Conference on Robotics, Automation and Mechatronics*, Vols 1 and 2. NewYork, USA, pp. 97-101.

Christensen, D. S. (1998). The costs and benefits of the earned value management process. *Journal of Parametrics, 18*(2), 1–16.

CII (1987). Project Control for Construction. *Construction Industry Institute,* Publication 6–5, University of Texas at Austin, Austin, Texas.

CII, (2016) *Project controls community of practice charter (Approved March 11, 2014)* Retrieved from https://www.construction-institute.org/scriptcontent/cops-files/PCCOP-Charter.pdf retrieved: 3/14/16

Crandall, K. C., & Woolery, J. C. (1982). Schedule development under stochastic scheduling. *Journal of the Construction Division*, *108*(2), 321–329.

Creswell, J. W. (2003). A Framework for Design. In *Research Design: Qualitative, Quantitative and Mixed Methods Approaches* (2nd ed.)

Davidson, I.N., & Skibniewski, M.J., (1995). Simulation of automated data collection in buildings. *Journal of Computing in Civil Engineering*, *9*, 9–20.

De Falco, M., & Macchiaroli, R (1998). Timing of control activities in project planning. *International Journal of Project Management, 16(1),* 51–58.

De Lapp, J. A., Ford, D. N., Bryant, J. A., & Horlen, J. (2004). Impacts of CAD on design realization. *Engineering, Construction and Architectural Management, 11,* 284–291.

De Vaus, D. A. (2004). *Research Design in Social Research*. Location: Sage Publications.

Department of Defense (DoD). (1967). *Performance measurement for selected acquisitions* (Department of Defense Instruction, DODI-7000.2).

Defense Contract Management Agency - DoD (2006, October). *Earned value management implementation guide*. United States of America - Department of Defense.

Dutton, J., & Jackson, S. (1988). Discerning threats and opportunities. *Administrative Science Quarterly, 33,* 370–387.

Eisenhardt, K. M. (1989a). Making fast strategic decisions in high-velocity environments. *Academy of Management Journal*, 27, 299–343.

Eisenhardt, K. M. (1989b). Building theories with case study research. *Academy of Management Review, 14,* 532–550.

El-Omari, S., & Moselhi, O. (2011). Integrating automated data acquisition technologies for progress reporting of construction projects. *Automation in Construction, 20,* 699–705.

El-Mashaleh, M. S., O'Brien,W., & Kang, Y. (2006). The impact of IT use at the firm level: An empirical study of contractor performance. *A Report to the Center for Construction Industry Studies, the University of Texas at Austin, Austin Texas*.

Evgeniou, T. (2002). Information integration and information strategies for adaptive enterprises. *European Management Journal, 20,* 486–494.

Faridi, A. S., & El-Sayegh, S. M. (2006). Significant factors causing delay in the UAE construction industry. *Construction Management and Economics, 24,* 1167–1176.

Fleming, Q.W., Koppleman, J. M. (2000), *Earned Value Project Management,* 2nd ed. Project Management Institute, Newton Square, Pennsylvania.

Flyvbjerg, B., Holm M. S., & Buhl, S. (2002). Underestimating costs in public works projects. Error or lie? *Journal of American Planning Association., 68,* 279–296.

Flyvbjerg, B., Skamris Holm, M. K., & Buhl, S. L. (2005). How (in) accurate are demand forecasts in public works projects?: The case of transportation. *Journal of the American Planning Association*, *71*, 131–146.

Flyvbjerg, B. (2006). From nobel prize to project management: Getting risks right. *Project Management Journal*, *37*(3), 5–15

Froese, T. M. (2010). The impact of emerging information technology on project management for construction. *Automation in Construction, 19,* 531–538.

Fuchs P. A., Washer G. A., Chase S. B., & Moore M. (2004). Applications of laser-based instrumentation for highway bridges. *Journal of Bridge Engineering, 9,* 541–549.

Gallaher, M. (2004). *Cost analysis of inadequate interoperability in the U.S. capital facilities industry*, National Institute of Standards and Technology, Department of Commerce, NIST GCR 04-867.

Ghanem, A. G., & AbdelRazig, Y. A. (2006). A framework for real-time construction project progress tracking. *Earth and Space, 188*(112), pp. 1–8.

Gibson, G. E., Jr., & Whittington, D. A. (2009). Charrettes as a method for engaging industry in best practices research. *Journal of Construction Engineering and Management, 136,* 66–75.

Gilsinn D. E., Cheok G. S., Witzgall C., & Lytle A. (2005). *Construction object identification from LADAR scans: An experimental study using I-beams*. US Department of Commerce, Technology Administration, National Institute of Standards and Technology.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for quantitative research.* Chicago: Aldine Publishing Company .

Golparvar-Fard, M., Peña-Mora, F., & Savarese, S. (2009). D4AR–a 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication. *Journal of Information Technology in Construction, 14,* 129–153.

Goodrum, P. M., McLaren, M. A., & Durfee, A. (2006). The application of active radio frequency identification technology for tool tracking on construction job sites. *Journal of Automation in Construction, 15,* 292–302.

Gordon S. J., Lichti D., Stewart M. P., & Franke J. (2004). Modelling point clouds for precise structural deformation measurement. *XXth ISPRS Congress*, Istanbul, Turkey.

Grau, D., & Back, W. E., (2014, August). Improving the Accuracy and Timeliness of Project Outcome Predictions. CII Research Report 291-11.

Grau, D., & Back, W. E. (2015a). Instantaneous Project Controls. Research Summary No. 316-1, Construction Industry Institute (CII), Austin. Tex.

Grau, D., & Back, W. E. (2016). Instantaneous Project Controls. Research Report No. 316-11, Construction Industry Institute (CII), Austin. Tex.

Grau, D., & Back, W. E. (2015b). Predictability index: Novel metric to assess cost and schedule performance. *Journal of Construction Engineering and Management, 141*(12).

Griffis, F. H., Hogan, D. B., & Li, W. (1995). An analysis of the impacts of using three dimensional computer models in the management of construction. Research Rep. No. 106-11, Construction Industry Institute (CII), Austin, Tex.

Hayes, E. (1981). *The complete problem solvers*. Philadelphia: Franklin Institute Press.

Hazır, Ö. (2015). A review of analytical models, approaches and decision support tools in project monitoring and control. *International Journal of Project Management, 33* 808–815.

Henderson, J. C., & Lee, S. (1992). Managing i/s design teams: A control theories perspective. *Management Science, 38,* 757–777.

Howell, G., & Ballard, G. (1997). Lean construction factors affecting project success in the piping function. *Lean Construction,* 161–185

Hwang, S., & Liu, L. Y. (2010). BIM for integration of automated real-time project control systems. *Proceeding. Construction Research Congress*. 2010: Innovation for Reshaping Construction Practice (pp. 509-517). Reston, VA: Construction Institute of ASCE.

Ibrahim, Y. M., Lukins, T. C., Zhang, X., Trucco, E., & Kaka, A. P. (2009). Towards automated progress assessment of workpackage components in construction projects using computer vision. *Advanced Engineering Informatics, 23,* 93–103.

Isaac, S., & Navon, R. (2014). Can project monitoring and control be fully automated? *Construction Management and Economics, 32,* 495–505.

Isidore, L. J., & Back, W. E. (2002). Multiple simulation analysis for probabilistic cost and schedule integration. *Journal of Construction Engineering and Management, 128,* 211–219.

Jaselskis, E. J., Anderson, M. R., Jahren, C. T., Rodriguez, Y., & Njos, S. (1995). Radio-frequency identification applications in construction industry. *Journal of Construction Engineering and Management, 121,* 189–196.

Jaselskis, E. J., & Ashley, D. B. (1991). Optimal allocation of project management resources for achieving success. *Journal of Construction Engineering and Management, ASCE 117*(2), 321–340.

Jaselskis E. J., Cackler E. T., Walters R. C., Zhang J., & Kaewmoracharoen M. (2006). Using scanning lasers for real-time pavement thickness measurement. CTRE Project 05-205, National Concrete Pavement Technology Center, Iowa State University.

Johnson, R. E., & Clayton, M. J. (1998). The impact of information technology in design and construction: The owner's perspective. *Automation in Construction, 8,* 3–14.

Jones, J. W. (1993). High speed management: Time-based strategies for managers and irganizations. San Francisco, CA: JosseyBass.

Kang, Y., O'Brien, W. J., Thomas, S., & Chapman, R. E. (2008). Impact of information technologies on performance: Cross study comparison. *Journal of Construction Engineering and Management, 134,* 852–863.

Kang, Y., O'Brien, W., & O'Connor, J. (2012). Analysis of information integration benefit drivers and implementation hindrances. *Automation in Construction, 22,* 277–289.

Kerzner, H. (2003). *Project management: A systems approach to planning, scheduling and controlling* (8th ed.). New York: John Wiley and Sons, Inc..

Kim, B. C., & Reinschmidt, K. F. (2009). Probabilistic forecasting of project duration using Bayesian inference and the beta distribution. *Journal of Construction Engineering and Management, 135,* 178–186.

Kim, B. C., & Reinschmidt, K. F. (2010). Probabilistic forecasting of project duration using Kalman filter and the earned value method. *Journal of Construction Engineering and Management, 136,* 834–843.

Kim, B. C., & Reinschmidt, K. F. (2011). Combination of project cost forecasts in earned value management. *Journal of Construction Engineering and Management, 137,* 958–966.

Kim, E., Wells, W.G.J., & Duffey, M. (2003). A model for effective implementation of earned value management methodology. *International Journal of Project Management, 21*, 375–382.

Kiziltas S., Akinci B., Ergen E., & Tang, P (2008). Technological assessment and process implications of field data capture technologies for construction and facility/infrastructure management [Special issue]. *ITcon, 13*, 134–154

Koskela, L. (1992). *Application of the new production philosophy to construction*, CIFE Technical Report No. 72, Stanford University, Stanford, CA.

Kostelyk, J. D. (2012). *Project controls for engineering work in practice*. Masters Dissertation, University of Alberta.

Li, J., Moselhi, O., & Alkass, S. (2006). Internet-based database management system for project control. *Engineering, Construction and Architectural Management, 13,* 242–253

Lipman, R. (2009). Interoperability with CIS/2 and IFC, National Institute of Standards and Technology (NIST), NASCC BIM 102 for the Steel Fabricator – 1 April 2009, Phoenix, AZ.

Liu, L. Y. (1995). Digital data-collection device for construction site documentation. Proc., 2nd *Congress on Computing in Civil Engineering*, Atlanta, 1287–1293.

Liu, J. Y.-C., Chen, H. H.-G., Jiang, J. J., & Klein, G. (2010). Task completion competency and project management performance: The influence of control and user contribution. *International Journal of Project Management, 28,* 220–227.

Marcotte, P. (1990). Hastening justice: Biden committee studies task force plan to cut trial delay. *ABA Journal, 76,* 40.

Meredith, J. R., & Mantel, S., Jr. (2003). *Project management—A managerial approach*. New York: John Wiley and Sons, Inc.

Michalak, C. F. (1992). *Establishing project controls for international projects—The Esperanto of project controls*. Proceedings of the *36th Annual Meeting of AACE*.

Moselhi, O., Li, J., & Alkass, S. (2004). Web-based integrated project control system. *Construction Management and Economics, 22,* 35–46.

Mott MacDonald. (2002). *Review of large public procurement in the UK*. London.

Mulva, S. P., & Dai, J. (2012). Performance Assessment. Construction Industry Institute, 2012 Edition, Austin, Texas.

Naeni, L. M., Shadrokh, S., & Salehipour, A. (2011). A fuzzy approach for the earned value management. *International Journal of Project Management, 29,* 764–772.

Navon, R. (2005). An overview of automated project performance control research at the technion. In Proceedings, *Twenty Second International Symposium on Automation and Robotics in Construction*, Ferrara, Italy (pp. 25-38).

Navon, R., & Goldschmidt, E., (2003). Can labor inputs be measured and controlled automatically? *Journal of Construction Engineering and Management, 129,* 437–445.

Navon, R., & Haskaya, I. (2006). Is detailed progress monitoring possible without designated manual data collection?. *Construction Management and Economics*, *24*(12), 1225-1229.

Navon, R., & Sacks, R. (2007). Assessing research issues in automated project performance control (APPC). *Automation in Construction, 16*, 474–484.

Navon, R., & Shpatnitsky, Y. (2005). Field experiments in automated monitoring of road construction. *Journal of Construction Engineering and Management, 131,* 487–493.

O'Connor, J. T., & Yang, L. R. (2004). Project performance versus use of technologies at project and phase levels. *Journal of Construction Engineering and Management, 130,* 322–329.

Odeh, A. M., & Battaineh, H. T. (2002). Causes of construction delay: Traditional contracts. *International Journal of Project Management, 20,* 67–73.

Odeyinka, H. A., & Yusif, A. (1997). The causes and effects of construction delays on completion cost of housing projects in Nigeria. *Journal of Financial Management of Property and Construction, 2,* 31–44.

Plaza, M., & Turetken, O. (2009). A model-based DSS for integrating the impact of learning in project control. *Decision Support Systems, 47,* 488–499.

Project Management Institute (PMI). (2005). *Practice standard for earned value management.* Newton Square, PA: Project Management Institute Publication.

Project Management Institute (PMI). (2008). *A guide to the project management body of knowledge (PMBOK Guide)* (4th ed.). Newtown Square, PA: Project Management Institute.

Rasdorf, W. J., & Herbert, M. J. (1990a). Automated identification systems-focus on bar coding. *Journal of Computing in Civil Engineering, 4,* 279–296.

Rebolj, D., Babič, N. Č., Magdič, A., Podbreznik, P., & Pšunder, M. (2008). Automated construction activity monitoring system. *Advanced Engineering Informatics, 22,* 493–503.

Rojas, E., & Songer, A. (1999). Web-centric systems: A new paradigm for collaborative engineering. *Journal of Management Engineering, 15,* 39–45.

Rozenes, S., Vitner, G., & Spraggett, S. (2006). Project control: Literature review. *Project Management Journal, 37*(4), 5–14

Russell, A. (1993). Computerized daily site reporting. *Journal of Construction Engineering and Management, 119*(2), 385–402.

Sacks, R., & Harel, M. (2006). An economic game theory model of subcontractor resource allocation behavior. *Construction Management and Economics, 24,* 869–881.

Saidi, K. S., Lytle, A. M., & Stone, W. C. (2003). Report of the NIST workshop on data exchange standards at the construction job site. ISARC— *20th International Symposium on Automation and Robotics in Construction*, Techniesche Universiteit Eindhoven, Eindhoven, The Netherlands.

Simon, H. (1987). Making management decisions: The role of intuition and emotion. *Academy of Management Executive, 1,* 57–64.

Su, Y. Y., Hashash, Y. M. A., & Liu, L. Y. (2006). Integration of construction as-built data via laser scanning with geotechnical monitoring of urban excavation. *Journal of Construction Engineering and Management, 132,* 1234–1241.

Taneja, S., Akinci, B., Garrett, J. H., Soibelman, L., Ergen, E., Pradhan, A., & Anil, E. B. (2010). Sensing and field data capture for construction and facility operations. *Journal of Construction Engineering and Management, 137,* 870–881.

Tang, P., Huber, D., Akinci, B., Lipman, R., & Lytle, A. (2010). Automatic reconstruction of as-built building information models from laser-scanned point clouds: A review of related techniques. *Automation in Construction, 19,* 829–843.

Teizer J., Kim C., Haas C. T., Liapi K. A., & Caldas C. H. (2005). Framework for real-time three-dimensional modelling of infrastructure. Geology and Properties of Earth Materials, Transportation Research Board Natl Research Council, Washington, 177-186.

Thomas, H. (2000). Schedule Acceleration, Work Flow, and Labor Productivity. *Journal of Construction Engineering Management, 126*(4), 261–267.

Thomas, S. R., Macken, C. L., & Lee, S. H. (2001). Impacts of design/information technology on building and industrial projects. *Proceedings NIST GCR*, 01-828.

Thomas, S., Lee, S., Spencer, J., Tucker, R., & Chapman, R. (2004). Impacts of design/information technology on project outcomes. *Journal of Construction Engineering and Management, 130,* 586–597.

Vanhoucke, M. (2009). *Measuring time: Improving project performance using earned value management*. New York, NY: Springer Science+Businesss Media, LLC.

Vanhoucke, M. (2012). Measuring the efficiency of project control using fictitious and empirical project data. *International Journal of Project Management, 30,* 252–263.

Walker, D., & Betts, M. (1997). Information technology foresight: The future application of the World Wide Web in construction. *Proc., CIB W78: IT for Construction* Process Reengineering, James Cook University, Townsville, Australia, 399–407.

Warhoe, S.P. (2004) The basics of earned value management, *Transactions of AACE International* CSC.07.01–CSC.07.10.

Winch, G. M., (2002). *Managing construction projects*. Oxford, U.K.: Blackwell.

Yin, R. (1994). *Case study research: Design and methods*. Beverly Hills, CA: Sage Publications.

Yang, L. R., O'Connor, J. T., & Wang, C. C. (2006). Technology utilization on different sizes of projects and associated impacts on composite project success. *International Journal of Project Management, 24,* 96–105.

Yang, L. R., O'Connor, J. T., & Chen, J. H. (2007). Assessment of automation and integration technology's impacts on project stakeholder success. *Automation in Construction, 16,* 725–733.

Zhiliang, M., Heng, L., Shen, Q. P., & Jun, Y. (2004). Using XML to support information exchange in construction projects. *Automation in Construction, 13,* 629–637.

Zhiliang, M., Wong, K. D., Heng, L., & Jun, Y. (2005). Utilizing exchanged documents in construction projects for decision support based on data warehousing technique. *Automation in Construction, 14,* 405–412.

Zhai, D., Goodrum, P. M., Haas, C. T., & Caldas, C. H. (2009). Relationship between automation and integration of construction information systems and labor productivity. *Journal of Construction Engineering and Management, 135,* 746–753.

APPENDIX I

SURVEY 1—BATCH MODE SURVEY

Batch Mode Survey (Survey 3) Questionnaire

Project Controls Survey

Introduction

Construction Industry Institute (CII) Research Team 316 is working with the objective to provide best practice recommendations on how to efficiently implement Instantaneous Project Controls. Currently, the industry has indicated that it takes too long to collect project controls data. Current project controls data is lagging in the reporting cycle. The ability to respond in an efficient amount of time is hampered by this lag in reporting. As part of this research endeavor, this survey instrument aims at identifying prevalent project controls practices in the industry with or without an instantaneous component. RT316 has defined controls as a competency that encompasses the resources, procedures, and tools for the planning, monitoring, and controlling of all phases of the capital project lifecycle. This includes estimating, cost and schedule management, risk management, change management, earned value progressing, forecasting, quality, and other subtasks.

In accordance with CII research practices, all data collected will be treated as strictly confidential. Your response to this survey will not be shared, distributed, or disclosed. The PIs will ensure that CII non-disclosure policies are always enforced. The Principal Investigators for RT316 are:

Dr. David Grau
Assistant Professor
Ira A. Fulton Schools of Engineering
School of Sustainable Engineering and The Built Environment
Arizona State University

Dr. Ed Back
Professor
Department of Civil, Environmental, and Construction Engineering
The University of Alabama

Regarding the survey tool, please consider the following:
1. This survey will take no longer than 20 minutes to complete.

2. The survey is based on project specific information. Please answer the survey questions based on a project that you have been recently involved with. Use the exact same project to answer the questions throughout the survey.

3. Completion date: Please ensure all responses are completed by AUGUST 7th.

For questions or comments, please contact Dr. David Grau (Arizona State University) at david.grau@asu.edu

Project Controls Survey

Respondent Information

Please complete the following information about yourself, and specify if you are willing to participate in a follow-up interview.

1. Name:
2. E-mail:
3. Position Title:
4. Company Name:
5. Project roles or services provided by your organization. (Select all that apply)
   - ☐ Owner/Client ☐ Contractor ☐ Engineering/Design ☐ Architectural ☐ Consultant
   - ☐ Procurement ☐ Construction Management ☐ Don't Know
   - ☐ Other services, please specify
6. How many years of experience within the capital projects industry do you have?
7. How many years of substantive project controls/management experience do you possess?

Project Controls Survey

Project Characteristics

Please answer the following questions for a completed or ongoing project that you have been involved with. Please select a recent projects that you are very familiar with in order to be able to accurately and rapidly respond to survey questions.

8. What was the sector affiliation for the project?
   - ○ Public Sector ○ Private Sector ○ Both

9. Was the project third party financed?
   - ○ Yes ○ No ○ In part or to some extent ○ Don't Know

10. Was your company/organization new to the geographic location/region?
    - ○ Yes ○ No

11. Select the GENERAL Industry Sector for the project. (Select all that apply)
    - ☐ Heavy Industrial
    - ☐ Light Industrial
    - ☐ Buildings
    - ☐ Infrastructure
    - ☐ Don't Know
    - ☐ If other sector, please specify

12. If you answered Heavy Industrial on Question 9, please specify the specific sectors.
    - ☐ Chemical Manufacturing ☐ Electrical (Generating) ☐ Environmental
    - ☐ Metals Refining/Processing ☐ Mining ☐ Tailing
    - ☐ Natural Gas Processing ☐ Oil/Gas Exploration/Production (well-site) ☐ Oil Refining
    - ☐ Oil Sands Mining/Extraction ☐ Oil Sands SAGD ☐ Oil Sands Upgrading
    - ☐ Cogeneration ☐ Pulp and Paper
    - ☐ If other Heavy Industrial sector, please specify

13. If you answered Light Industrial on Question 9, please specify the specific sectors.
    - ☐ Automotive Manufacturing ☐ Consumer Products Manufacturing
    - ☐ Foods ☐ Microelectronics Manufacturing
    - ☐ Office Products Manufacturing ☐ Pharmaceutical Manufacturing
    - ☐ Pharmaceutical Labs ☐ Pharmaceutical Warehouse
    - ☐ Clean Room (Hi-Tech)
    - ☐ If other Light Industrial sector, please specify

14. If you answered Buildings on Question 9, please specify the specific sectors.
    - ☐ Communication Center ☐ Courthouse ☐ Dormitory/Hotel/Housing/Residential
    - ☐ Embassy ☐ Low Rise Office (<=3 floors) ☐ High Rise Office (<3 floors)
    - ☐ Hospital ☐ Laboratory ☐ Maintenance Facilities
    - ☐ Movie Theatre ☐ Parking Garage ☐ Physical Fitness Center
    - ☐ Prison ☐ Restaurant/Nightclub ☐ Retail Building
    - ☐ School ☐ Warehouse
    - ☐ If other Building sector, please specify

15. If you answered Infrastructure on Question 9, please specify the specific sectors.
    - ☐ Airport ☐ Central Utility Plant ☐ Electrical Distribution
    - ☐ Flood Control ☐ Highway (including heavy haul road) ☐ Marine Facilities
    - ☐ Navigation ☐ Process Control ☐ Rail
    - ☐ Tunneling ☐ Water/Wastewater ☐ Telecom, Wide Area Network
    - ☐ Pipeline ☐ Tank Farms ☐ Gas Distribution
    - ☐ If other Infrastructure sector, please specify

16. Project nature. (Select all that apply)
    - ☐ Grass Roots, Greenfield
    - ☐ Brownfield (co-locate)
    - ☐ Modernization, Renovation, Upgrade (changes to existing capacity)
    - ☐ Addition, Expansion
    - ☐ Don't Know
    - ☐ If Other, please specify

17. What was the regulatory/legal constraints of this project when compared against an average project?
    - ○ Many ○ Average ○ Few ○ None/NA

18. If the project is no yet completed, please enter current percentage of project completion. (%)

19. What was the approved completion time for this project? (enter value in months)

20. Please specify the actual start date for this project.

mm/dd/yyyy

21. Please specify the actual or projected completion date.

mm/dd/yyyy

22. What was the baseline budget (including contingency) for this project? (Please enter value in millions of US dollars, e.g. 3.6 Million)

23. What was the contingency cost in the budget for this project? (Please enter value in millions of US dollars, e.g. 0.5 Million)

24. What was the actual total installed cost for this project. (Please enter value in millions of US dollars, e.g. 3.5 Million)

25. Where is the project located?

- United States
- Canada
- Western Europe
- Eastern Europe
- Asia
- Middle East
- Central America
- South America
- Africa
- Oceania

26. What was the delivery method for this project?

- Design-Bid-Build (Traditional)
- Design-Build (EPC)
- Construction Management at Risk
- Parallel Primes
- Development
- Fast Track
- Turnkey
- If Other, please describe

27. What was the contract type? (Select all that apply)

- Lump Sum
- Guaranteed Maximum Price (GMP)
- Unit Price
- Cost Plus Fixed Fee
- Time and Materials
- Don't Know
- Other, please specify

28. What functions were procured during the project? (check all that apply)

- Materials
- Equipment
- Subs
- Direct Labor

29. What was the most common weekly workload?

- 40 hrs./week
- 50 to 60 hrs./week
- 24 Hours, 7 days a week
- If other, please specify

30. Was there a new technology or process in this project?

- Yes
- No

31. If your answer is "Yes", assess the level of familiarity with the new technology or process during design and execution?

- High
- Medium
- Low

32. What was the organization of the Project Controls team?

- Cost Controller and Scheduler
- Project Controller (Whom does both)

33. Considering the organizational hierarchy, how many levels of controllers were involved in controlling the project? (e.g. senior project controller, cost controller, and junior schedule controller would encompass 3 levels of staff within the organizational hierarchy)

34. To how many different internal or external stakeholders were project controls reported to?

35. What was the project controls office structure for the project?

- Central Project Controls Office
- Local Project Controls Office
- Both Central and Local Offices

36. On average, how many equivalent full-time employees (FTE) worked to control the status of the projects?

- None or less than 1
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11 to 15
- 16 to 20
- 21 or more

37. Was there a project controls function with at least daily reporting frequency?

- NO
- YES
- If YES, please identify such control functions

Project Controls Survey

Information Systems

38. Please complete the information on the following computer systems utilized in this project.

	Do you use this software?	Name of Software:	Level of Software Customization:
Building Information Modeling (BIM) or any other Object-Oriented Modeling software	-- Please Select --		-- Please Select --
Enterprise Resource Planning (ERP) Software	-- Please Select --		-- Please Select --
Scheduling Software	-- Please Select --		-- Please Select --
Cost Estimating Software	-- Please Select --		-- Please Select --
Accounting Software	-- Please Select --		-- Please Select --
Change Management Software	-- Please Select --		-- Please Select --
Progress Tracking Software	-- Please Select --		-- Please Select --
Procurement Software	-- Please Select --		-- Please Select --
Document Management Software	-- Please Select --		-- Please Select --

39. Please identify which of the Software Functions listed in the question above are integrated (or inter-connected) and, if so, how they are integrated?
For example: Costing software is inter-connected to P6 and cost loaded schedules are updated weekly by importing an xml file from Oracle.

40. Does your company integrate the information in the Building Information Model (BIM) or any other Object-Oriented Modeling software within the project controls system with the purpose to control the project?

-- None --

41. If you answered YES to the previous question, please briefly describe how the information in the Building Information Model (BIM) or any other Object-Oriented Modeling software, is used for project control purposes?
For example: BIM information was used to validate construction put in place such as duct work or piping.

Information Systems

42. Please complete the information on the following computer systems utilized in this project.

	Do you use this software?	Name of Software:	Level of Software Customization:
Building Information Modeling (BIM) or any other Object-Oriented Modeling software	-- Please Select --		-- Please Select --
Enterprise Resource Planning (ERP) Software	-- Please Select --		-- Please Select --
Scheduling Software	-- Please Select --		-- Please Select --
Cost Estimating Software	-- Please Select --		-- Please Select --
Accounting Software	-- Please Select --		-- Please Select --
Change Management Software	-- Please Select --		-- Please Select --
Progress Tracking Software	-- Please Select --		-- Please Select --
Procurement Software	-- Please Select --		-- Please Select --
Document Management Software	-- Please Select --		-- Please Select --

43. Please identify which of the Software Functions listed in the question above are integrated (or inter-connected) and, if so, how they are integrated?
For example: Costing software is inter-connected to P6 and cost loaded schedules are updated weekly by importing an xml file from Oracle.

44. Does your company integrate the information in the Building Information Model (BIM) or any other Object-Oriented Modeling software within the project controls system with the purpose to control the project?

-- None --

45. If you answered YES to the previous question, please briefly describe how the information in the Building Information Model (BIM) or any other Object-Oriented Modeling software, is used for project control purposes?
For example: BIM information was used to validate construction put in place such as duct work or piping.

Project Controls for ENGINEERING DESIGN

46. Were control functions used during the Engineering Design phase of the project?

- ○ Yes
- ○ No
- ○ Don't Know

Project Controls for ENGINEERING DESIGN

In this page you are asked questions regarding the Control functions used during the Engineering Design phase of the project, and in terms of Cost, Schedule, Scope, and Quality.

COST CONTROLS DURING ENGINEERING DESIGN

47. Please assess the frequency of data collection to feed the following COST control functions during ENGINEERING DESIGN.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget	○	○	○	○	○	○	○	○	○	○
Monitor Committed Cost (actual obligated/contracted cost to perform work)	○	○	○	○	○	○	○	○	○	○
Monitor/Control Change Order Cost	○	○	○	○	○	○	○	○	○	○
Monitor Budget (Baseline Plus Approved Change Order)	○	○	○	○	○	○	○	○	○	○
Monitor Actual Expenditures (actual engineering cost to date)	○	○	○	○	○	○	○	○	○	○
Plan/Control Estimate to Complete for current engineering phase	○	○	○	○	○	○	○	○	○	○
Monitor Engineering Performance (earned value progressing) - performed vs planned	○	○	○	○	○	○	○	○	○	○
Plan/Monitor Risk Analysis (should include all risks & outstanding changes)	○	○	○	○	○	○	○	○	○	○
Estimate the Total Engineering Cost for all engineering phases	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Payable	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Receivable	○	○	○	○	○	○	○	○	○	○
Monitor/Control estimated Total Installed Cost	○	○	○	○	○	○	○	○	○	○

48. If known, what is the age of the reported COST information to the PROJECT MANAGER during ENGINEERIGN DESIGN for each of the following control functions?

(For example, the reported information can be one week, one month, or two months old -respective to the moment when the raw data was collected)

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget	○	○	○	○	○	○	○	○	○	○
Monitor Committed Cost (actual obligated/contracted cost to perform work)	○	○	○	○	○	○	○	○	○	○
Monitor/Control Change Order Cost	○	○	○	○	○	○	○	○	○	○
Monitor Budget (Baseline Plus Approved Change Order)	○	○	○	○	○	○	○	○	○	○
Monitor Actual Expenditures (actual engineering cost to date)	○	○	○	○	○	○	○	○	○	○
Plan/Control Estimate to Complete for current engineering phase	○	○	○	○	○	○	○	○	○	○
Monitor Engineering Performance (earned value progressing) - performed vs planned	○	○	○	○	○	○	○	○	○	○
Plan/Monitor Risk Analysis (should include all risks & outstanding changes)	○	○	○	○	○	○	○	○	○	○
Estimate the Total Engineering Cost for all engineering phases	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Payable	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Receivable	○	○	○	○	○	○	○	○	○	○
Monitor/Control estimated Total Installed Cost	○	○	○	○	○	○	○	○	○	○

49. If known, what is the age of the reported COST information during ENGINEERING DESIGN to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget										
Monitor Committed Cost (actual obligated/contracted cost to perform work)										
Monitor/Control Change Order Cost										
Monitor Budget (Baseline Plus Approved Change Order)										
Monitor Actual Expenditures (actual engineering cost to date)										
Plan/Control Estimate to Complete for current engineering phase										
Monitor Engineering Performance (earned value progressing) - performed vs planned										
Plan/Monitor Risk Analysis (should include all risks & outstanding changes)										
Estimate the Total Engineering Cost for all engineering phases										
Monitor Accounts Payable										
Monitor Accounts Receivable										
Monitor/Control estimated Total Installed Cost										

SCHEDULE CONTROLS DURING ENGINEERING DESIGN

50. Please assess the frequency of data collection to feed the following TIME control functions during ENGINEERING DESIGN.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Engineering performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

51. If known, what is the age of the reported TIME information to the PROJECT MANAGER during ENGINEERIGN DESIGN for each of the following control functions?

(For example, the reported information can be one week, one month, or two months old -respective to the moment when the raw data was collected)

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Engineering performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

52. If known, what is the age of the reported TIME information during ENGINEERING DESIGN to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Engineering performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

SCOPE CONTROLS DURING ENGINEERING DESIGN

53. Please assess the frequency of data collection to feed the following SCOPE control functions during ENGINEERING DESIGN.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

54. If known, what is the age of the reported SCOPE information to the PROJECT MANAGER during ENGINEERIGN DESIGN for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

55. If known, what is the age of the reported SCOPE information during ENGINEERING DESIGN to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

Project Controls Survey

Project Controls for PROCUREMENT

56. Were control functions used during the Procurement phase of the project?

- ◯ Yes
- ◯ No
- ◯ Don't Know

Project Controls for PROCUREMENT

In this page you are asked questions regarding the Control functions used during the Procurement phase of the project, and in terms of Cost, Schedule, Scope, and Quality.

COST CONTROLS DURING PROCUREMENT

57. Please assess the frequency of data collection to feed the following COST control functions during PROCUREMENT.

	Instantaneous	**Hourly**	**Daily**	**Weekly**	**Bi-Weekly**	**Monthly**	**Bi-Monthly**	**Quarterly or More**	**Not Controlled**	**Don't Know**
Plan Baseline/Control Budget	○	○	○	○	○	○	○	○	○	○
Monitor Committed Cost (actual obligated/contracted cost to perform work)	○	○	○	○	○	○	○	○	○	○
Monitor/Control Change Order Cost	○	○	○	○	○	○	○	○	○	○
Monitor Budget (Baseline Plus Approved Change Order)	○	○	○	○	○	○	○	○	○	○
Monitor Actual Expenditures (actual engineering cost to date)	○	○	○	○	○	○	○	○	○	○
Plan/Control Estimate to Complete for all phases	○	○	○	○	○	○	○	○	○	○
Monitor Procurement Performance (earned value progressing) - performed vs planned	○	○	○	○	○	○	○	○	○	○
Plan/Monitor Risk Analysis (should include all risks & outstanding changes)	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Payable	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Receivable	○	○	○	○	○	○	○	○	○	○
Monitor/Control estimated Total Installed Cost	○	○	○	○	○	○	○	○	○	○

58. If known, what is the age of the reported COST information to the PROJECT MANAGER during PROCUREMENT for each of the following control functions?

(For example, the reported information can be one week, one month, or two months old -respective to the moment when the raw data was collected)

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget										
Monitor Committed Cost (actual obligated/contracted cost to perform work)										
Monitor/Control Change Order Cost										
Monitor Budget (Baseline Plus Approved Change Order)										
Monitor Actual Expenditures (actual engineering cost to date)										
Plan/Control Estimate to Complete for all phases										
Monitor Procurement Performance (earned value progressing) - performed vs planned										
Plan/Monitor Risk Analysis (should include all risks & outstanding changes)										
Monitor Accounts Payable										
Monitor Accounts Receivable										
Monitor/Control estimated Total Installed Cost										

59. If known, what is the age of the reported COST information during PROCUREMENT to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget	○	○	○	○	○	○	○	○	○	○
Monitor Committed Cost (actual obligated/contracted cost to perform work)	○	○	○	○	○	○	○	○	○	○
Monitor/Control Change Order Cost	○	○	○	○	○	○	○	○	○	○
Monitor Budget (Baseline Plus Approved Change Order)	○	○	○	○	○	○	○	○	○	○
Monitor Actual Expenditures (actual engineering cost to date)	○	○	○	○	○	○	○	○	○	○
Plan/Control Estimate to Complete for all phases	○	○	○	○	○	○	○	○	○	○
Monitor Procurement Performance (earned value progressing) - performed vs planned	○	○	○	○	○	○	○	○	○	○
Plan/Monitor Risk Analysis (should include all risks & outstanding changes)	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Payable	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Receivable	○	○	○	○	○	○	○	○	○	○
Monitor/Control estimated Total Installed Cost	○	○	○	○	○	○	○	○	○	○

SCHEDULE CONTROLS DURING PROCUREMENT

60. Please assess the frequency of data collection to feed the following TIME control functions during PROCUREMENT.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Procurement Performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

61. If known, what is the age of the reported TIME information to the PROJECT MANAGER during PROCUREMENT for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Procurement performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

62. If known, what is the age of the reported TIME information during PROCUREMENT to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Procurement performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

SCOPE CONTROLS DURING PROCUREMENT

63. Please assess the frequency of data collection to feed the following SCOPE control functions during PROCUREMENT.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Bid Tracking Log (Item, Bidders, Request For Proposal, Responses Received, Bid Tab, etc.)	○	○	○	○	○	○	○	○	○	○
Monitor Purchase Order Tracking Log (Item, PO #, Vendor, Vendor Data Progress, Fast Delivery Date)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

64. If known, what is the age of the reported SCOPE information to the PROJECT MANAGER during PROCUREMENT for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Bid Tracking Log (Item, Bidders, Request For Proposal, Responses Received, Bid Tab, etc.)	○	○	○	○	○	○	○	○	○	○
Monitor Purchase Order Tracking Log (Item, PO #, Vendor, Vendor Data Progress, Fast Delivery Date)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

65. If known, what is the age of the reported SCOPE information during PROCUREMENT to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Bid Tracking Log (Item, Bidders, Request For Proposal, Responses Received, Bid Tab, etc.)	○	○	○	○	○	○	○	○	○	○
Monitor Purchase Order Tracking Log (Item, PO #, Vendor, Vendor Data Progress, Fast Delivery Date)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

QUALITY CONTROLS DURING PROCUREMENT

66. Please assess the frequency of data collection to feed the following QUALITY control functions during PROCUREMENT.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections	○	○	○	○	○	○	○	○	○	○
Quality and Turnaround of Requests for Information (RFIs)	○	○	○	○	○	○	○	○	○	○

67. If known, what is the age of the reported QUALITY information to the PROJECT MANAGER during PROCUREMENT for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections	○	○	○	○	○	○	○	○	○	○
Quality and Turnaround of Requests for Information (RFIs)	○	○	○	○	○	○	○	○	○	○

68. If known, what is the age of the reported QUALITY information during PROCUREMENT to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections	○	○	○	○	○	○	○	○	○	○
Quality and Turnaround of Requests for Information (RFIs)	○	○	○	○	○	○	○	○	○	○

Project Controls Survey

Project Controls for CONSTRUCTION

In this page, you are kindly requested to answer questions on project controls for CONSTRUCTION in terms of cost, schedule, scope, and quality.

69. Were control functions used during the Construction phase of the project?

- ◯ Yes
- ◯ No
- ◯ Don't Know

Project Controls Survey

Project Controls for CONSTRUCTION

In this page you are asked questions regarding the Control functions used during the Construction phase of the project, and in terms of Cost, Schedule, Scope, and Quality.

COST CONTROLS DURING CONSTRUCTION

70. Please assess the frequency of data collection to feed the following COST control functions during CONSTRUCTION.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor committed Cost (actual obligated/contracted cost to perform work)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor/Control Change Order Cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Budget (Baseline Plus Approved Change Order)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Actual Cost/Expenditures to Date (including OT)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Estimate Total Installed Cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Construction Performance Measurement - performed vs planned (hours & quantities)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Risk Analysis (should include contingency reconciliation)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Accounts Payable	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Accounts Receivables	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

71. If known, what is the age of the reported COST information to the PROJECT MANAGER during CONSTRUCTION for each of the following control functions?

71. If known, what is the age of the reported COST information to the PROJECT MANAGER during CONSTRUCTION for each of the following control functions?

(For example, the reported information can be one week, one month, or two months old -respective to the moment when the raw data was collected)

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget										
Monitor committed Cost (actual obligated/contracted cost to perform work)										
Monitor/Control Change Order Cost										
Monitor Budget (Baseline Plus Approved Change Order)										
Monitor Actual Cost/Expenditures to Date (including OT)										
Estimate Total Installed Cost										
Monitor Construction Performance Measurement - performed vs planned (hours & quantities)										
Monitor Risk Analysis (should include contingency reconciliation)										
Monitor Accounts Payable										
Monitor Accounts Receivables										

72. If known, what is the age of the reported COST information during CONSTRUCTION to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget										
Monitor committed Cost (actual obligated/contracted cost to perform work)										
Monitor/Control Change Order Cost										
Monitor Budget (Baseline Plus Approved Change Order)										
Monitor Actual Cost/Expenditures to Date (including OT)										
Estimate Total Installed Cost										
Monitor Construction Performance Measurement - performed vs planned (hours & quantities)										
Monitor Risk Analysis (should include contingency reconciliation)										
Monitor Accounts Payable										
Monitor Accounts Receivables										

SCHEDULE CONTROLS DURING CONSTRUCTION

73. Please assess the frequency of data collection to feed the following TIME control functions during CONSTRUCTION.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Construction performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

74. If known, what is the age of the reported TIME information to the PROJECT MANAGER during CONSTRUCTION for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Construction Performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

75. If known, what is the age of the reported TIME information during CONSTRUCTION to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Construction performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

SCOPE CONTROLS DURING CONSTRUCTION

76. Please assess the frequency of data collection to feed the following SCOPE control functions during CONSTRUCTION.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

77. If known, what is the age of the reported SCOPE information to the PROJECT MANAGER during CONSTRUCTION for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

78. If known, what is the age of the reported SCOPE information during CONSTRUCTION to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)	○	○	○	○	○	○	○	○	○	○
Monitor Change Order Status	○	○	○	○	○	○	○	○	○	○
Monitor Change Order impact to project schedule and cost	○	○	○	○	○	○	○	○	○	○

QUALITY CONTROLS DURING CONSTRUCTION

79. Please assess the frequency of data collection to feed the following QUALITY control functions during CONSTRUCTION.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections - Include here or in cost	○	○	○	○	○	○	○	○	○	○
Quality and Turnaround of Requests for Information (RFIs)	○	○	○	○	○	○	○	○	○	○
Rework Hours / Costs	○	○	○	○	○	○	○	○	○	○
Design Omissions	○	○	○	○	○	○	○	○	○	○
Design Errors	○	○	○	○	○	○	○	○	○	○
Constructability	○	○	○	○	○	○	○	○	○	○

80. If known, what is the age of the reported QUALITY information to the PROJECT MANAGER during CONSTRUCTION for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections - Include here or in cost	○	○	○	○	○	○	○	○	○	○
Quality and Turnaround of Requests for Information (RFIs)	○	○	○	○	○	○	○	○	○	○
Rework Hours / Costs	○	○	○	○	○	○	○	○	○	○
Design Omissions	○	○	○	○	○	○	○	○	○	○
Design Errors	○	○	○	○	○	○	○	○	○	○
Constructability	○	○	○	○	○	○	○	○	○	○

81. If known, what is the age of the reported QUALITY information during CONSTRUCTION to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections - Include here or in cost	○	○	○	○	○	○	○	○	○	○
Quality and Turnaround of Requests for Information (RFIs)	○	○	○	○	○	○	○	○	○	○
Rework Hours / Costs	○	○	○	○	○	○	○	○	○	○
Design Omissions	○	○	○	○	○	○	○	○	○	○
Design Errors	○	○	○	○	○	○	○	○	○	○
Constructability	○	○	○	○	○	○	○	○	○	○

Project Controls for COMMISSIONING AND STARTUP

In this page, you are kindly requested to answer questions on project controls for COMMISSIONING AND STARTUP in terms of cost, schedule, scope, and quality.

82. Were control functions used during the Commissioning and Startup phase of the project?

- ◯ Yes
- ◯ No
- ◯ Don't Know

Project Controls for COMMISSIONING AND STARTUP

In this page you are asked questions regarding the Control functions used during the Commissioning and Startup phase of the project, and in terms of Cost, Schedule, Scope, and Quality.

COST CONTROLS DURING COMMISSIONING AND STARTUP

83. Please assess the frequency of data collection to feed the following COST control functions during COMMISSIONING AND STARTUP.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor committed Cost (actual obligated/contracted cost to perform work)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor/Control Change Order Cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Budget (Baseline Plus Approved Change Order)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Actual Cost/Expenditures to Date (including Overtime)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Estimate Total Installed Cost	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Commissioning Performance Measurement - performed vs planned (hours & quantities)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Risk Analysis (should include contingency reconciliation)	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Accounts Payable	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯
Monitor Accounts Receivables	◯	◯	◯	◯	◯	◯	◯	◯	◯	◯

84. If known, what is the age of the reported COST information to the PROJECT MANAGER during COMMISSIONING AND STARTUP for each of the following control functions?

(For example, the reported information can be one week, one month, or two months old -respective to the moment when the raw data was collected)

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget	○	○	○	○	○	○	○	○	○	○
Monitor committed Cost (actual obligated/contracted cost to perform work)	○	○	○	○	○	○	○	○	○	○
Monitor/Control Change Order Cost	○	○	○	○	○	○	○	○	○	○
Monitor Budget (Baseline Plus Approved Change Order)	○	○	○	○	○	○	○	○	○	○
Monitor Actual Cost/Expenditures to Date (including Overtime)	○	○	○	○	○	○	○	○	○	○
Estimate Total Installed Cost	○	○	○	○	○	○	○	○	○	○
Monitor Commissioning Performance Measurement - performed vs planned (hours & quantities)	○	○	○	○	○	○	○	○	○	○
Monitor Risk Analysis (should include contingency reconciliation)	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Payable	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Receivables	○	○	○	○	○	○	○	○	○	○

85. If known, what is the age of the reported COST information during COMMISSIONING AND STARTUP to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Plan Baseline/Control Budget	○	○	○	○	○	○	○	○	○	○
Monitor committed Cost (actual obligated/contracted cost to perform work)	○	○	○	○	○	○	○	○	○	○
Monitor/Control Change Order Cost	○	○	○	○	○	○	○	○	○	○
Monitor Budget (Baseline Plus Approved Change Order)	○	○	○	○	○	○	○	○	○	○
Monitor Actual Cost/Expenditures to Date (including Overtime)	○	○	○	○	○	○	○	○	○	○
Estimate Total Installed Cost	○	○	○	○	○	○	○	○	○	○
Monitor Commissioning Performance Measurement - performed vs planned (hours & quantities)	○	○	○	○	○	○	○	○	○	○
Monitor Risk Analysis (should include contingency reconciliation)	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Payable	○	○	○	○	○	○	○	○	○	○
Monitor Accounts Receivables	○	○	○	○	○	○	○	○	○	○

SCHEDULE CONTROLS DURING COMMISSIONING AND STARTUP

86. Please assess the frequency of data collection to feed the following TIME control functions during COMMISSIONING AND STARTUP.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Commissioning performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

87. If known, what is the age of the reported TIME information to the PROJECT MANAGER during COMMISSIONING AND STARTUP for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Commissioning performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

88. If known, what is the age of the reported TIME information during COMMISSIONING AND STARTUP to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Monitor Major Milestone Progress / Commissioning performance against Baseline Schedule	○	○	○	○	○	○	○	○	○	○
Estimated Time to Completion	○	○	○	○	○	○	○	○	○	○

SCOPE CONTROLS DURING COMMISSIONING AND STARTUP

89. Please assess the frequency of data collection to feed the following SCOPE control functions during COMMISSIONING AND STARTUP.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)										
Monitor Change Order Status										
Monitor Change Order impact to project schedule and cost										

90. If known, what is the age of the reported SCOPE information to the PROJECT MANAGER during COMMISSIONING AND STARTUP for each of the following control functions?

	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)									
Monitor Change Order Status									
Monitor Change Order impact to project schedule and cost									

91. If known, what is the age of the reported SCOPE information during COMMISSIONING AND STARTUP to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Develop Control Scope (Baseline Scope plus Approved Change Orders)									
Monitor Change Order Status									
Monitor Change Order impact to project schedule and cost									

QUALITY CONTROLS DURING COMMISSIONING AND STARTUP

92. Please assess the frequency of data collection to feed the following QUALITY control functions during COMMISSIONING AND STARTUP.

	Instantaneous	Hourly	Daily	Weekly	Bi-Weekly	Monthly	Bi-Monthly	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections	○	○	○	○	○	○	○	○	○	○

93. If known, what is the age of the reported QUALITY information to the PROJECT MANAGER during COMMISSIONING AND STARTUP for each of the following control functions?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections	○	○	○	○	○	○	○	○	○	○

94. If known, what is the age of the reported QUALITY information during COMMISSIONING AND STARTUP to the person with the ULTIMATE AUTHORITY at the CLIENT ORGANIZATION?

	Instantaneous	One Hour	One Day	One Week	Two Weeks	One Month	Two Months	Quarterly or More	Not Controlled	Don't Know
Quality Tests and Inspections	○	○	○	○	○	○	○	○	○	○

Project Controls Survey

Feedback

95. Please provide any other comments, or clarification to your responses that may be of interest to the researchers. Any type of information that can help us understand a specific context or perspective on your responses will be much appreciated. For instance, if your responses are provided from a very specific perspective on cost, schedule, or quality only.

96. Last, please provide any comments on the survey questions and content. For instance, on the questions or concepts that may have been unclear to you.

APPENDIX II

SURVEY 2—INSTANTANEOUS PROJECT CONTROLS SURVEY

Survey Questionnaire

Introduction

The Construction Industry Institute (CII) has sponsored Research Team 316 (RT316) with the objective to provide recommended practices to efficiently implement Instantaneous Project Controls. Currently, CII member companies have indicated that it frequently takes too long to collect project data and to assess project trends and status. The ability to effectively respond in a timely manner to project trends and events is actually hampered by the inability to identify, monitor, and respond to such events and trends in a timely manner. Thus, as part of the RT316 research endeavor, this survey instrument aims at identifying examples of Instantaneous Controls within CII member companies. To enable such identification, RT316 has defined Instantaneous Controls as a control function on the scope, cost, schedule, or quality of a project characterized by: 1) a continuous feed of data (input); and 2) an on demand and accurate reporting (output) capability.

In accordance with CII research practices, all data collected will be treated as strictly confidential. Your response to this survey will not be shared, distributed, or disclosed. The PIs will ensure that CII non-disclosure policies are always enforced. The Principal Investigators for RT316 are:

Dr. David Grau
Assistant Professor
Ira A. Fulton Schools of Engineering
School of Sustainable Engineering and The Built Environment
Arizona State University

Dr. Ed Back
Professor
Department of Civil, Environmental, and Construction Engineering
The University of Alabama

Regarding the survey tool, please consider the following:
1. This survey will take no longer than 20 minutes to complete.

2. No specific project data or detailed preparation is required.

3. Since the timing for the controls reporting cycle varies within an organization by the layer at which information is reported, we kindly ask multiple survey responses to be completed in your organization by experts in three different functions:
• Project managers
• Field and office project controllers
• Corporate managers

4. Completion date: Please ensure all responses are completed by JULY 3rd.

For questions or comments, please contact Dr. David Grau (Arizona State University) at david.grau@asu.edu

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Respondent Information

PLEASE COMPLETE THE FOLLOWING INFORMATION ABOUT WORK POSITION AND EXPERIENCE.

1. Name:

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2. E-mail:

---

3. Position Title:

---

4. Company Name:

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5. How many years of experience within the capital projects industry do you possess?

6. How many years of substantive project controls/management experience do you possess?

☐

PLEASE ANSWER THE FOLLOWING QUESTIONS ABOUT YOUR COMPANY AND ON THE TYPE(S) OF PROJECT YOU ARE TYPICALLY INVOLVED WITH.

7. Project roles or services provided by your organization. (Select all that apply)

- ☐ Owner/Client
- ☐ Contractor
- ☐ Engineering/Design
- ☐ Architectural
- ☐ Consultant
- ☐ Procurement
- ☐ Construction Management
- ☐ Other services, please specify

8. Select the GENERAL Industry Sector(s) for the projects you are typically involved with. (Select all that apply)

- ☐ Heavy Industrial
- ☐ Light Industrial
- ☐ Buildings
- ☐ Infrastructure
- ☐ If Other, please specify

9. If you selected Heavy Industrial in Question 8, please identify the specific project sectors you are typically involved with. (Select all that apply)

- ☐ Chemical Manufacturing
- ☐ Electrical (Generating)
- ☐ Environmental
- ☐ Metals Refining/Processing
- ☐ Mining
- ☐ Tailing
- ☐ Natural Gas Processing
- ☐ Oil/Gas Exploration/Production (well-site)
- ☐ Oil Refining
- ☐ Oil Sands Mining/Extraction
- ☐ Oil Sands SAGD
- ☐ Oil Sands Upgrading
- ☐ Cogeneration
- ☐ Pulp and Paper
- ☐ If other Heavy Industrial sector, please specify

10. If you selected Light Industrial in Question 8, please identify the specific project sectors you are typically involved with. (Select all that apply)

- ☐ Automotive Manufacturing
- ☐ Consumer Products Manufacturing
- ☐ Foods
- ☐ Microelectronics Manufacturing
- ☐ Office Products Manufacturing
- ☐ Pharmaceutical Manufacturing
- ☐ Pharmaceutical Labs
- ☐ Pharmaceutical Warehouse
- ☐ Clean Room (Hi-Tech)
- ☐ If other Light Industrial sector, please specify

11. If you selected Buildings in Question 8, please identify the specific project sectors you are typically involved with. (Select all that apply)

- ☐ Communication Center
- ☐ Courthouse
- ☐ Dormitory/Hotel/Housing/Residential
- ☐ Embassy
- ☐ Low Rise Office (<=3 floors)
- ☐ High Rise Office (<3 floors)
- ☐ Hospital
- ☐ Laboratory
- ☐ Maintenance Facilities
- ☐ Movie Theatre
- ☐ Parking Garage
- ☐ Physical Fitness Center
- ☐ Prison
- ☐ Restaurant/Nightclub
- ☐ Retail Building
- ☐ School
- ☐ Warehouse
- ☐ If other Buildings sector, please specify

12. If you selected Infrastructure in Question 8, please identify the specific project sectors you are typically involved with. (Select all that apply)

- ☐ Airport
- ☐ Central Utility Plant
- ☐ Electrical Distribution
- ☐ Flood Control
- ☐ Highway (including heavy haul road)
- ☐ Marine Facilities
- ☐ Navigation
- ☐ Process Control
- ☐ Rail
- ☐ Tunneling
- ☐ Water/Wastewater
- ☐ Telecom, Wide Area Network
- ☐ Pipeline
- ☐ Tank Farms
- ☐ Gas Distribution
- ☐ If other Infrastructure sector, please specify

13. Please specify the nature of the projects you are typically involved with. (Select all that apply)

- ☐ Grass Roots, Greenfield
- ☐ Brownfield (co-locate)
- ☐ Modernization, Renovation, Upgrade (changes to existing capacity)
- ☐ Addition, Expansion
- ☐ If Other, please specify

14. What is the most common contract method(s) for the projects you are typically involved with? (Select all that apply)

- Lump Sum
- Guaranteed Maximum Price (GMP)
- Unit Price
- Cost Plus Fixed Fee
- Time and Materials
- Other, please specify

15. What is the most common project delivery method(s) for the projects you are typically involved with? (Select all that apply)

- Design-Bid-Build
- Design-Build (EPC)
- CM at Risk
- Parallel Primes
- Other, please specify

16. What is the most common project priority(s) for the projects you are typically involved with? (Select all that apply)

- Cost
- Schedule
- Balanced
- Other, please specify

17. What is the most common buisiness driver(s) for the projects you are typically involved with? (Select all that apply)

- Quality
- Capacity
- Risk
- Operability
- Environmental
- Social
- Other, please specify

18. Identify the geographical location(s) for the projects you are typically involved with. (Select all that apply)

- United States
- Canada
- Western Europe
- Eastern Europe
- Asia
- Middle East
- Central America
- South America
- Africa
- Oceania

19. Please select the range(s) of Total Installed Costs for the projects you are typically inolved with? (Select all that apply)

- Less than $1 million
- $1 to $10 million
- $10 to $100 million
- $100 to $500 million
- $500 million to $1billion
- $1 to $10 billion
- More than $10 billion

20. How many equivalent full-time employees (FTE) work, on average, to control the status of the projects with the Total Installed Costs reported in Question 19?

If you find difficult to assess a concrete number -for example, in the case of dealing with multiple projects with very different ranges of Total Installed Costs that require a very differect number of FTE- please provide your comments in the textbox below. For instance, you can mention that for a specific range of Total Installed Costs, a given number of FTE in controls is common according to your experience.

- None or less than 1
- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11 to 15
- 16 to 20
- 21 or more
- Comments, if needed:

21. Common project controls office structure for the projects you are typically involved with.

- Central Project Controls Office
- Local Project Controls Office
- Both Central and Local Offices
- If other, such that the controls structure varies per projects, please specify

Project Information Systems

PLEASE ANSWER THE QUESTIONS BELOW REGARDING SOFTWARE INFORMATION SYSTEMS USE AND SOFTWARE IMPLEMENTATION STRATEGIES TO SUPPORT THE PROJECTS YOU ARE TYPICALLY INVOLVED WITH.

22. Please complete the information on the following computer systems utilized to support the projects you are typically involved with.

	Is this software used?	Name of Software:	Level of Software Customization:
Building Information Modeling (BIM) or any other Object-Oriented Modeling software	--Please Select--		--Please Select--
Enterprise Resource Planning (ERP) software	--Please Select--		--Please Select--
Scheduling software	--Please Select--		--Please Select--
Cost Estimating software	--Please Select--		--Please Select--
Accounting software	--Please Select--		--Please Select--
Change Management software	--Please Select--		--Please Select--
Progress Tracking software	--Please Select--		--Please Select--
Procurement software	--Please Select--		--Please Select--
Document Management software	--Please Select--		--Please Select--

23. Please identify which of the Software Functions listed in the question above (Question 22) are integrated for project control purposes and, if so, please briefly describe how they are integrated.

For example: Design quantities extracted from the Building Information Model are compared with installed quantities to assess productivity progress and trends.

24. Does your company use the data in the Building Information Model (BIM) or any other Object-Oriented Modeling software for project control purposes?

--None--

25. If you answered YES to Question 24, please briefly describe how the data in the Building Information Model (BIM) or any other Object-Oriented Modeling software is used for project control purposes.

Click on the "Insert" button to add an item here.
Click on the "New Pg" button to add an item here on a new page.

Identification of Instantaneous Control Function(s)

AS A REMINDER, INSTANTANEOUS PROJECT CONTROLS IS DEFINED AS A CONTROL FUNCTION ON THE SCOPE, COST, SCHEDULE, OR QUALITY OF A PROJECT CHARACTERIZED BY: 1) A CONTINUOUS FEED OF DATA (INPUT); AND 2) AN ON DEMAND AND ACCURATE REPORTING (OUTPUT) CAPABILITY.

THIS SURVEY AIMS AT IDENTIFYING INSTANTANEOUS CONTROL FUNCTIONS, ACCORDING TO THE ABOVE DEFINITION, WITHIN CII MEMBER COMPANIES. THEREFORE THE NEXT TWO QUESTIONS WILL HELP US DETERMINE WHETHER THERE IS ONE OR MORE EXAMPLES OF INSTANTANEOUS CONTROL FUNCTION(S) IN THE PROJECTS YOU ARE INVOLVED WITH.

26. To the best of your knowledge, is there one or more controls function(s) (in cost, schedule, quality, or scope) for which data is continuously, or at least daily, collected? Just as an example, expenditure or cost data is often collected on an ongoing basis or at very short intervals of time.

○ Yes ○ No ○ Don't Know

27. **Is there one or more control function(s) (in cost, schedule, quality, or scope) for which its status can be reported in near real-time, on-demand, or at least on a daily basis? The answer to this question is critical to this survey. We ask you to carefully evaluate your answer.**

TIP. *Think broadly. To this date, we have found evidence of daily reporting functions related to construction trends and progress, construction-related quality tests and inspections, commissioning and startup tests and inspections, schedule progress, cost progress, or materials status to name a variety of examples. Thus, carefully assess whether you can identify a function with at least daily reporting.*

○ Yes ○ No ○ Don't Know

Information about an Instantaneous Control function

SINCE WE HAVE IDENTIFIED THAT THERE IS ONE OR MORE INSTANTANEOUS CONTROL FUNCTIONS IN THE PROJECTS YOU WORK WITH, THE QUESTIONS IN THIS PAG INQUIRE ABOUT A SPECIFIC (ONLY ONE) SUCH INSTANTANEOUS CONTROL FUNCTION. IN THE FIRST QUESTION, THUS, WE ASK YOU TO IDENTIFY SUCH INSTANTANEOUS CONTROL FUNCTION, WHILE THE REMAINING QUESTIONS IN THE PAGE INQUIRES ON THE SAME FUNCTION.

28. Please specifically identify the Instantaneous Control function (only one) you want to report in the rest of this tab.

29. What is the project phase(s) for which the Instantaneous Control function (identified in Question 28) is utilized? (Select all that apply)

- Engineering
- Procurement
- Construction
- Commissioning and Startup

30. What computing systems or software tools are used to support the previously identified Instantaneous Control function? (Select all that apply)

- Enterprise Resource Planning
- Schedule software
- Cost Estimating software
- Accounting software
- Change Management software
- Progress Tracking software
- Procurement software
- Document Management software
- Building Information Modeling or other Object-Oriented Modeling software
- If other, please specify

31. Select the Department(s) or roles responsible to execute the previously identified Instantaneous Control function. (Select all that apply)

- Field Project Management
- Office Project Management
- Field Project Controls
- Office Project Controls
- If other, please specify

32. Select the Department or role(s) responsible for the maintenance of the systems and processes that support the Instantaneous Control function. (Select all that apply)

- Project Management
- Project Controls
- Information Technologies
- If other, please specify

33. To the best of your knowledge, how many equivalent full time employees (FTE) are required to maintain the Instantaneous Control function?

34. How is the data collected for the Instantaneous Control function?

- Manual
- Semi-automated, with manual support
- Automated

35. How often is the data collected?

- Instantaneous
- Hourly
- Daily
- Other, please specify

36. How is the data reported?

- Paper Copy Submittal
- Electronic Output
- Automatic Update Report

37. How is the reported-information generated from the raw data?

- Manually generated
- Semi-manually generated with the help of computers (for instance with copy-paste or with spreadsheets)
- Automatically generated

38. Select the Department or role(s) to which the generated-information is reported to. (Select all that apply)

- Project Management
- Field Project Controls
- Office Project Controls
- Corporate Management
- Client / Owner
- Third Party Financing Organization
- If other, please specify

39. How frequent is the generated-information reported for the Instantaneous Control function?

- Instantaneous
- Hourly
- Daily
- Other, please specify

40. What is the age of the reported information to the project manager?

- One Hour
- One Day
- One Week
- Two Weeks
- One Month
- Two Months
- Quarterly or More
- Don´t Know

41. What is the age of the reported information to the person who has the ultimate authority at the owner/client company?

- One Hour
- One Day
- One Week
- Two Weeks
- One Month
- Two Months
- Quarterly or More
- Don´t Know

42. For how many years has your company used this Instantaneous Control function?

- Less than 2 years
- 2 to 5 years
- 6 to 10 years
- 10 to 15 years
- More than 15 years
- Other, please comment:

43. How would you rate the effectiveness of the Instantaneous Control function to control project performance?

- Very Low Effectiveness
- Low Effectiveness
- Medium Effectiveness
- High Effectiveness
- Very High Effectiveness

44. Do you know of additional Instantaneous Control functions within your organization in addition to the function identified above?

- Yes
- No

45. If you ansered YES to Question 44, please identify these additional Instantaneous Control functions in your ogranization. In case you answered NO, please skip this question and move to the next one.

46. RT316 is committed to deliver the best value to CII member companies by reaching to subject matter experts like you. Hence, we would like to know if you would be available for a follow-up interview on the Instantaneous Controls function that you have reported. Please respond yes or no.

- Yes, I am available for a follow-up interview.
- No, I am not.

Personal Assessment of Barriers and Benefits to Instantaneous Controls

BASED ON YOUR EXPERIENCE AND EXPERTISE, THIS PAGE WILL INQUIRE ON YOUR PERCEIVED BARRIERS AND BENEFITS TO INSTANTANEOUS CONTROL FUNCTIONS. AS SUCH, PLEASE REMIND THAT INSTANTANEOUS PROJECT CONTROLS IS DEFINED AS A CONTROL FUNCTION ON THE SCOPE, COST, SCHEDULE, OR QUALITY OF A PROJECT CHARACTERIZED BY: 1) A CONTINUOUS FEED OF DATA (INPUT); AND 2) AN ON DEMAND AND ACCURATE REPORTING (OUTPUT) CAPABILITY.

47. Based on the above Instantaneous Controls definition, please identify the **TOP FIVE BARRIERS** to the implementation of Instantaneous Control functions.

- Lack of information integration (e.g. through a common information system or database).
- Lack of a standard data exchange protocols (across information systems such as ERP, materials, procurement, etc.).
- Lack of automated data analytics (e.g. part or all information automatically analyzed without human intervention).
- Lack of a common cost coding structure (e.g. across estimating, design-engineering, and execution).
- Delayed data acquisition and / or data input.
- Turnover / instability within the project team.
- Inadequate project team experience and skills.
- Lack of project team alignment.
- Late (not early enough) project team involvement in the project.
- Unwillingness to disclose accurate / actual data (e.g. 2 sets of books).
- Lack of transparency and trust among project stakeholders.
- Negative influence of personal incentives towards data disclosure.
- Unclear return on investment (ROI) from Instantaneous Project Controls
- Resistance to change current project controls methods, manuals, or procedures.
- Lack of awareness and understanding on the potential in current control software tools towards instantaneous control functions.
- Varying needs among different projects (e.g. project types, sizes, location, contract strategies, etc...).
- Lack of corporate leadership support and vision towards instantaneous controls.
- Lack of project team support to facilitate the implementation of instantaneous project controls.
- Different control requirements and needs among owner, contractor, and regulatory agencies.
- Lack of trust in project controls reporting functions.
- Other(s), please specify

48. Based on the above Instantaneous Controls definition, please identify the **TOP FIVE BENEFITS** from the implementation of Instantaneous Control functions.

- Improved resource allocation.
- Focus on critical project metrics.
- Reliable and timely decision making by project managers.
- Reliable and timely decision making by corporate managers.
- Data integration and standardization.
- Consistent and timely data, with an implicit emphasis on data quality.
- Improved cost performance.
- Improved schedule performance.
- Improved quality performance.
- Improved scope control.
- Improved capital allocation across portfolio of projects.
- Reliable and rapid validation of information through access to recently collected data.
- Risk mitigation.
- Legal dispute avoidance.
- Non-adversarial relationships among project stakeholders.
- Shift towards analyzing information vs. collecting data.
- Project stakeholder alignment.
- Other(s), please specify

49. From the perspective of your position, please assess the **potential positive impact on COST performance** that the implementation of Instantaneous Control functions could bring within each project phase.

Consider both the potential cost savings from instanteneous (or at least daily) reporting control functions, and also the costs incurred to implement such instantaneous control functions at each project phase.

	Extremely High Positive Cost Impact	High Positive Cost Impact	Moderate Positive Cost Impact	Somewhat Positive Cost Impact	Null Positive Cost Impact
Design / Engineering	○	○	○	○	○
Procurement	○	○	○	○	○
Construction	○	○	○	○	○
Commissioning and Startup	○	○	○	○	○

50. From the perspective of your position, please assess the **potential positive impact on SCHEDULE performance** that the implementation of Instantaneous Control functions could bring within each project phase. Thus, think to what extent instataneous (or at least daily) reporting can expedite completion time, and assess the potential impact on the completion time for each project phase separately.

	Extremely High Positive Schedule Impact	High Positive Schedule Impact	Moderate Positive Schedule Impact	Somewhat Positive Schedule Impact	Null Positive Schedule Impact
Design / Engineering	○	○	○	○	○
Procurement	○	○	○	○	○
Construction	○	○	○	○	○
Commissioning and Startup	○	○	○	○	○

51. From the perspective of your position, please assess the **potential positive impact on QUALITY performance** that the implementation of Instantaneous Control functions could bring within each project phase. Thus, think to what extent instataneous (or at least daily) reporting can improve quality performance, and assess the potential impact on quality at each project phase separately.

	Extremely High Positive Quality Impact	High Positive Quality Impact	Moderate Positive Quality Impact	Somewhat Positive Quality Impact	Null Positive Quality Impact
Design / Engineering	○	○	○	○	○
Procurement	○	○	○	○	○
Construction	○	○	○	○	○
Commissioning and Startup	○	○	○	○	○

52. From the perspective of your position, please assess the **potential positive impact on SCOPE CONTROL performance** that the implementation of Instantaneous Control functions could bring within each project phase. Thus, think to what extent instataneous (or at least daily) reporting can enhance scope control, and assess the potential impact on scope control at each project phase separately.

	Extremely High Positive Scope Control Impact	High Positive Scope Control Impact	Moderate Positive Scope Control Impact	Somewhat Positive Scope Control Impact	Null Positive Scope Control Impact
Design / Engineering	○	○	○	○	○
Procurement	○	○	○	○	○
Construction	○	○	○	○	○
Commissioning and Startup	○	○	○	○	○

Feedback

PLEASE PROVIDE FEEDBACK ON THE SURVEY IN THE QUESTIONS BELOW.

53. Please provide any other comments, or clarification to your responses that may be of interest to RT316. Any type of information that can help us understand a specific context or perspective on your responses will be much appreciated. For instance, if your responses are provided from a very specific perspective on cost, schedule, or quality only.

54. Last, please provide any comments on the survey questions and content. For instance, on the questions or concepts that may have been unclear to you.

APPENDIX III

PRE-INTERVIEW EMAIL TO COMPANIES

→ Join Lync Meeting

Join by phone
+18666384279 FREE (USA) English (United States)
Find a local number

Conference ID: 6965783

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[!OC([1033])!]

Essential Question to be Addressed

The ability to gather and analyze project controls information instantaneously would constitute a meaningful breakthrough for project execution. What methods and measures could be developed to collect and analyze project controls information in real time?

Background

The industry has indicated that it takes too long to collect project controls data. Current project controls data is lagging in the reporting cycle. The ability to respond in an efficient amount of time is hampered by this lag in reporting. How do we go from reactive to proactive in this regard?

1. Can you give us an example where your operation has systems and processes that rely on Instantaneous information? Please describe how the information is used in your operation.
2. What was the original business problem or business objective when you established the system.
3. Is your system linked to other corporate systems e.g., ERP system?
4. Are your clients or suppliers feeding or using the information for your system?
5. How often do you input data or how often is data updated automatically?
6. How frequently do you report out using the system?
7. Who on the team uses the data and what decisions do they make using the date. E.g, manufacturing schedules, etc.
8. What are the primary benefits of the system?
9. What were the original barriers to adopting the system?
10. What are current challenges you experience with the system?
11. How do you motivate or incentivize your clients/ suppliers to updated data and utilize instantaneous data?
12. If systems and processes were available, what other real time data collection and feedback would you implement?
13. Do you have any plans (short-term or long term) to enhance your system?
14. Who is your technology partner on this system, or are their industry leading vendors in this space?
15. Can you provide a system flow diagram that show how information is input processed and out using the system?
16. How much cost or FTEs are necessary to maintain the system on an annual basis?