IDENTIFICATION OF PHASE-BASED KEY PERFORMANCE FACTORS AND THEIR BEST PRACTICES IN CONSTRUCTION PROJECTS

by

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Abstract

THE IDENTIFICATION OF PHASE-BASED KEY PERFORMANCE FACTORS

AND THEIR BEST PRACTICES IN CIVIL PROJECTS

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Delay and cost overrun in construction projects are two widespread problems arousing practitioners' and scholars' concerns as poor time and cost performance lead construction projects to failure. It is estimated that more than half of the construction industry's projects encounter significant cost overruns and major delays, resulting in the industry having a tarnished reputation. Despite the attempts of numerous researchers to identify key performance factors, their results have been inconsistent. Most of the literature has focused solely on the construction phase budget and time overruns; the engineering/design and procurement phase costs and schedule performances have been rarely studied. Therefore, the objective of this study is to primarily identify the Key Performance Factors (KPF) in Engineering, Procurement and Construction (EPC) phases and calculate the weight impact associated with each of the identified KPFs. The second aim of this research is to find the most appropriate Best Practices (BPs) for the top-ranked phase-based KPFs. In this regard, a comprehensive review of existing literature was performed. The results of the literature review were utilized to develop a detailed survey collecting comprehensive data of the recent completed construction projects. In the meantime, various statistical analysis methods including two sample T-test and

Kruskal-Wallis test were utilized to analyze the collected data. Then, Epsilon-Squared effect size method was applied to prioritize the identified KPFs. The outcomes of this study address the potential confusion of the industry's practitioners related to the inconsistent list of potential KPFs and their best practices, and pave the way for the construction research community to conduct future performance-related studies.

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Chapter 1

Introduction

The construction industry is a major contributor to a nation's economy. In the United Arab Emirates (UAE), it contributes 14% of the gross domestic product (GDP) (Faridi and El-Sayegh, 2006). It is a complex industry that is constantly changing (Lee et al. 2001) from the very first stage of a project to its completion, as it involves several parties, a vast range of processes with many inputs, and multiple phases (Prakash & Nandhini, 2015). The success of a construction project can be attributed to efficient implementation of three important phases: the engineering/design phase, the procurement phase, and the construction phase (Ballard, 1993; Mahmoud-Jouini, 2004; Yeo and Ning 2002). The construction performance in each phase is affected by three main attributes: time, cost, and quality (The Iron Triangle) (Atkinson, 1999; Chua et al. 1999; Munns and Bjeirmi, 1996). However, since quality is abstract and difficult to define, it receives the least attention, even outside the construction industry (Mintzberg, 1982).

1.1. What is Delay and Cost Overrun

Delays in the construction industry are defined as time overruns, either beyond the stated date in the contract or beyond the date that the parties agreed upon for the delivery of the project (O'Brien, 1976). Unfortunately, few projects are completed on time (Assaf and Al-Hejji, 2006), and the delays often increase the cost of the project, causing disputes and claims between the owner and the contractor (Ahmed et al. 2003). Minor delays are often neglected because they develop slowly during the construction process, but their cumulative effect impacts the project financially (Ahmed et al. 2003).

Cost escalation is the gap between the actual cost of project, defined at the completion stage of the project, and the budget forecasted before starting the project.

The magnitude of cost overruns and delays with respect to the initial estimated value varies from country to country, industry to industry, project to project, and time to time (Habibi et al. 2017). Approximately 70% of the construction projects in the private and public sectors experience delay, with the average time overrun of 10% to 30% of the original duration in Saudi Arabia (Assaf and Al-Hejji, 2006). The study of public infrastructure projects implemented from 2000 to 2008 in Jordan revealed that the average percentage of overrun time and overrun cost was 226% and 214%, respectively (Al-Hazim et al. 2017).

1.2. Problem Statement

Despite the fact that many researchers devoted their resources and time to assess the Key Performance Factors (KPFs) in terms of schedule and cost, construction industry is still suffering from inconsistent lists of KPFs, as the findings of each study is different from the others.

Moreover, although extensive research has been conducted to identify the causes behind construction performance and to devise mitigation measures, few studies have focused on phase-based performance causes and strategies. Herein, construction phase has been the center of attention in the literature and as a result, the significance of engineering and procurement phases were almost disregarded in the construction industry.

According to literature, the issue of poor performance was mostly examined in building, underground, and infrastructure projects and just a few researchers concentrated on the industrial projects.

1.3. Goals and Objectives

The primary goal of this study is to improve performance of construction projects in different EPC phases. To serve this purpose, the problems should be recognized first and then, the correct course of actions should be proposed to the construction industry. Hence, the objective of this study is to critically examine the existing research efforts related to performance and to develop a survey to address the issues of time and cost overruns. The results of this study provide a list of key performance factors and best practices to minimize time and cost overruns during all EPC phases. Apart from providing a list of significant phase-based performance factors, this study also aims to calculate and prioritize the weight impacts associated with the identified key performance factors in each of the EPC phases and then, to find appropriate BPs for the top weighted performance factors.

1.4. Research Hypothesis

To verify the schedule/cost performance factors that truly describe project performance, the significance in differentiating good performance projects from poor performance projects was statistically tested. If a performance factor was not statistically significant, it was excluded from further analysis. Details about statistical tests, methods and also the significance level (α) were discussed in the data analysis section. The main research hypothesis was proposed to statistically test the significance of schedule/cost performance factors. The hypothesis is as follows:

Null Hypothesis (H0) – The identified phase-based performance factors are not significant in differentiating good performance projects and poor performance projects.

Alternative Hypothesis (H1) – The identified phase-based performance factors are significant in differentiating good performance projects and poor performance projects.

The second research hypothesis of this research is to examine if identified phase-based best practices truly describe the key performance factors of the relevant phase. Like the first hypothesis, if any of the best practices was not statistically significant for describing the examined phase and the relevant performance factors, it was excluded from the list. The following research hypothesis was proposed:

Null Hypothesis (H0) – The identified best practices are not significant in addressing/preventing the issues resulting from the key performance factors

Alternative Hypothesis (H1) – The identified best practices are significant in addressing/preventing the issues resulting from the key performance factors

1.5. Contribution

The findings of this study not only can help construction practitioners to identify the most significant schedule/cost performance factors and the appropriate best practices in different EPC phases, but also will enable them to make proper decisions in difficulties to address or prevent potential performance issues. Furthermore, these findings help construction experts to allocate their resources to relevant phases and activities and save a large amount of time and money. The findings of this study also provide guidance for academic scholars to conduct further research and give insight on phase-based construction cost and schedule performance in other construction projects including building, infrastructure and underground projects.

1.6. Thesis Layout

In summary, chapter one of this thesis gives a general introduction about the importance of the research topic and the problem statement, objectives, research hypothesis and contributions of this research for future work. Chapter two provides an extensive literature review about the past efforts for identification of performance factors and their best practices in different EPC phases. Chapter 3 explains the research methodology. A vast range of data and information were collected through literature review and presented in chapter 4. By means of the collected data, a detailed and structured survey was developed and distributed to construction practitioners. Chapter 5 discusses the questionnaire in detail. In chapter 6, different data analyses are utilized to assess the results of respondents and finally in chapter 7, conclusion is drawn and recommendations are given for future studies. It should be noted that the complete list of the performance factors and abbreviations used in this study are presented in the appendix B section of the research.

Chapter 2

Literature Review

2.1. Engineering Phase

The pre-construction phase of projects can be divided into two parts: project conception and project design. Project conception is the recognition of a need that can be satisfied by a physical structure. The project design phase translates the primary concept into an expression of a spatial form that will satisfy the client's requirements in an optimum economic manner" (Okpala and Aniekwu, 1988). However, Al-Reshaid et al. (2005) emphasized that the three basic phases of the pre-construction period are: (1) the planning (pre-design) phase; (2) design phase; and (3) tendering and award phase. The planning phase mainly covers the initial costs of estimating, preliminary scheduling, and control program updating, which is addressed by PM/CM consultants in the monthly reports. In addition, the design phase can refer to detailed design scheduling, milestone allocations and updating, and schedule monitoring and follow-up. Shrestha and Mani (2012) also declared that engineering/consulting firms prepare designs, drawings and specifications during the detailed design phase.

Despite numerous attempts to identify critical schedule performance factors in the construction phase, only a few researchers have focused on the engineering/design phase (Yang and Wei 2010). Since delays in the engineering phase can cause serious problems to the completion of the project, it is important to perform a delay analysis to find critical schedule performance factors in the initial phase (Al-Saggaf 1998).

Engineering phase schedule performance factors

Engineering-related time overruns occur because of problems in design development, preparation and/or approval of workshop drawings, and/or changes in the parties involved. Design development is the most important engineering activity in the life of a project (Marzouk et al. 2008) because this is when the engineers try to identify and meet the owners' and final-users' expectations for a favorable outcome (Larsen et al. 2015). Shop drawings are a set of drawings that describe design documents in detail, the preparation of which is the responsibility of contractor (Marzouk et al. 2008). Some studies concluded that insufficient basic project data and a delay in the preparation, submission, and approval process of shop drawings can negatively affect the schedule and cost performance of these two groups (Assaf et al. 1995, Mezher and Tawil 1998, Yang and Wei, 2010). Also, any changes requested by one of the contracting parties may cause delays in the project's completion (Marzouk et al. 2008). Yang and Wei, (2010), identified changes in the client's requirements as the single most significant cause for time overruns in the planning and design phases for public construction projects in Taiwan. Engineering design changes, for which the clients are responsible, are almost inevitable in the construction industry (Mohamad et al 2012). Any additions, omissions, or modifications to the scope of the work can be attributed to these changes (Akinsola et al., 1997; Kermanshachi, 2017; Turner, 1984). According to the Love and Li (2000), these changes cause additional work and duplication of efforts, and can be resolved by quality management practices and by thorough coordination of project documentation during the development of the design. Most of the time, these changes incur excessive claims and disputes, and cause delays in both the design and construction phases of the project (Mohamad et al 2012).

Some researchers focused on the impact of design management as one of the most important factors in improving schedule performance. Baldwin et al. (1999) stated that a better understanding of the information flow among all involved parties can improve design management. Lack of sufficient design management may also generate incompatible construction information and details, causing delays to the completion of projects. Sambasivan and Soon (2007) concluded that lack of communication during the planning stage between owners, consultants, contractors, and subcontractors can have negative effects on the schedule performance of a project.

Kog et al. (1999) studied the importance of frequent meetings between the project manager and other involved parties, along with the amount of time the project manager devoted to the project, financial incentives provided to the designer, and the project manager’s experience with projects of a similar scope. Marzouk et al. (2008) conducted a study to identify the main causes of engineering-related delays in Egypt. Some of their findings included mistakes/changes in the design documents or shop drawings; delays in responding to contractor’s queries; delays in the preparation process due to lack of resources, experience, management, etc.; delays due to unforeseen problems in the shop drawings.

Cost performance factors of engineering phase

The design fee is normally related to the size and complexity of the project and often is a percentage of the total estimated cost (Manavazhi and Xunzhi 2001). In this regard, complexity has been defined as one the major criteria which affects project cost performance (Dao et al. 2017) which should be assed and measured prior to the initiation of each construction project (Dao et al. 2016). Although the actual cost of the engineering phase is relatively small, its impact on the project cost is the greatest (Paulson 1976). As a result, slight inefficiencies during the design phase can have serious implications on the life-cycle costs of the project (Kermanshachi, 2016; Manavazhi and Xunzhi, 2001).

A project might face different problems because of inaccurate, incomplete, or untimely information (Sanvido and Norton, 1994), which can affect the efficiency of the design process (Manavazhi and Xunzhi, 2001). A study by Manavazhi and Xunzhi (2001) revealed that revision of the design is an integral part of every construction project and it can increase the cost of design phase because of limitations of time, cost, and unavailability of experienced designers. Based on the study by Mohamad et al. (2012), design changes are a crucial part of construction and significantly affect the costs of the different EPC phases. The clients and design teams are often responsible for them, especially in fast-track projects. Sometimes clients are forced to change the scope of work due to financial pressures, lack of ability to imagine the proposed work, and/or quality or performance enhancement. Due to the relationship between time and cost, delays imposed by these problems can change the cost performance (Al-Saggaf, 1998; Mohamad et al. 2012).

Kuprenas (2003) analyzed more than 270 completed engineering design projects in Los Angeles, CA, and examined the effects of the project management process on the cost performance of the design phase. He declared that frequent design team meetings and progress updates are two of the most critical performance factors which, if neglected, might increase the cost of the design phase. He also concluded that training the project manager and using project-management-based organizational structure were not significant in reducing design costs.

2.2. Procurement Phase

While the procurement phase represents the post-engineering phase, it is also considered a pre-construction phase in EPC projects (Yeo & Ning, 2006) and is comprised of complex processes that occur in different locations (Mulholland & Christian, 1999). These processes include receiving engineering drawings from consultants, documenting and issuing requests for proposals (RFPs) or quotations (RFQs), bidding between vendor and bidder, placing orders, fabricating and assembling equipment, testing, delivery, and shipping (Yeo & Ning, 2006). Sourcing, purchasing, contracting, and on-site material management are the contractor's main procurement activities. Contractors also should procure the required equipment and materials based on engineering documents during the procurement phase (Nethery, 1989). In addition, there are other activities which should be dealt with in procurement phase including an array of bureaucracy-related details at many administrative levels; approval checks; fragmentation of laws on procurement; high levels of corruption; and lack of coherence between procurement systems, local culture, administrative systems, and authority structure. These processes usually cause projects to face cost escalation, time overruns, and inefficiency (Toor & Ogunlana, 2008).

Schedule performance factors of procurement phase

Procuring resources is a critical task in the procurement phase. Unavailability of material, equipment, and skilled labor imposes many obstacles to an effective performance (Ogunlana et al. 1996; Enshassi et al. 2009; Sambasivan and Soon, 2007; Kermanshachi et al. 2017). Sambasivan and Soon (2007) developed a questionnaire that they distributed to their clients, consultants, and contractors to assess the main causes of delays and their effects on the Malaysian construction industry. They concluded that shortage of materials, inadequate labor supply, and lack of availability of equipment availability and equipment failure are among the ten significant factors that can hamper the progress of project and force it to experience delays and cost overruns. According to Manavazhi & Adhikar's (2002) study, a 0.5% overrun of total budgeted cost is routinely imposed by material and equipment procurement in highway projects in Nepal.

According to Assaf et al. (1995) and Mezher and Tawil (1998), material-related factors which affect the performance of a project can be attributed to material shortage, material changes, transportation and shipment, impairment, and manufacturing of materials. Among these material-related factors, material shortage is cited most often as a KPF in many studies (Alaghbari et al. 2012; Chan and Kumaraswamy 1997; Okpala and Aniekwu, 1988; Sambasivan and Soon, 2007). As mentioned by Sambasivan and Soon (2007), in some developing countries like Indonesia, where demand exceeds supply, the prices of materials rise and force contractors to postpone purchases until the price goes down. Moreover, based on Said and El-Rayes' (2010) study, a disproportion of material procurement and available storage on the construction site can also create problems. Neglecting the important interdependency between material procurement and available storage space may cause serious implications pertaining to material shortages, improper storage, poor and unsafe site layouts, and productivity losses, all of which cause project delays (Bell and Stukhart, 1987; Jang et al. 2007; Thomas et al. 1989).

Equipment, especially capital equipment, has different characteristics and requirements than bulk material procurement. By comparing the major equipment procurement with material procurement, Yeo & Ning (2006) expressed that capital equipment procurement has a longer lead-time and higher unit procurement cost, and usually requires specific technology for assembly. Equipment shortages, accompanied by poorly maintained equipment, especially during the construction seasons, can lead the project to failure or cause it to deviate from the estimated schedule (Assaf et al. 1995; Mezher and Tawil 1998; Sambasivan and Soon 2007). Equipment shortages occur for different reasons. Due to the growth of the economy in many developing countries, the price of equipment increases, and contractors who rely only on rental equipment suffer from below-standard machinery. Overextension of resources is another cause of delay for those contractors who own the equipment, and sometime, independent contractors wait too long for equipment to be transferred from another site (Ogunlana et al. 1996). Faridi and El-Sayegh (2006) underlined that the productivity and reliability of equipment can affect every single step of construction.

Cost performance factors of procurement phase

The fluctuation of prices is the most important factor causing cost overruns where there is no uncontrollable delay, and it is directly related to the rate of inflation. The excessive demand for supplies, material shortages, and lack of a unified cost adjustment formula in the industry impose an unstable inflationary trend that results in fluctuations in the prices of materials, labor, and services (Okpala and Aniekwu, 1988; Mansfield et al. 1994; Khodahemmati, 2018). The exchange rate is another factor affecting material costs in the marketplace. Since some construction materials are imported, the low value of local currency places some restrictions and increases the cost of imported materials (Ameh et al. 2010). Contacting a local supplier can neutralize the effect of excessive price fluctuations related to imported resources while putting the local currency in a stable situation (Mansfield et al. 1994).

Thomas et al. (2005) asserted that material management is an imperative factor in managing productivity and controlling the cost of the site. As he said, “Site material management is defined as the allocation of delivery, storage, and handling spaces and resources for the purpose of supporting the labor force and minimizing inefficiencies due to congestion and excess material movement.” As Thomas & Smith (1992) mentioned, the lack of site material management can reduce daily productivity of a construction project up to 40%. Thomas et al. (2005) divided construction sites into three zones: semipermanent, exterior storage; staging areas; and workface interior storage to address the problem of poor material management causing considerable waste in time and money.

2.3. Construction Phase

According to Okpala and Aniekwu (1988), the construction phase consists of operations that create the physical form of design and satisfy the project's conception. Le-Hoai et al. (2008) believed that although the causes of delays and cost overruns can be attributed to all phases of a construction project, the main problems emerge during the construction phase. On the other hand, many researchers discussed the importance of the engineering phase (Liao et al. 2011; Shrestha and Mani, 2012; Yang and Wei, 2010). Many projects start the construction phase before the construction drawings have been completed by the architects/engineers. Consequently, there is partial overlapping between the design phase and the construction phase (Kometa, et al. 1994). Due to this overlap, the performance of either these two phases can affect that of the other phase. Hence, the performance of the construction phase relies on the quality of the design. If design errors are not minimized, they can increase the construction cost and delay the completion of project (Shrestha and Mani 2012). The constructability of the design is another factor that can cause the time/cost performance of the construction phase to deviate from the baseline. Lack of construction knowledge during the design process prevents contractors from beginning construction and has serious implications to the project performance in terms of time and cost (Kog et al. 1999). A report by the National Economic Development Office (NEDC, 1987) indicated that more than 50% of the problems experienced during the construction phase are related to poor design information.

Schedule performance factors of construction phase

Construction is among the largest economic activities in some developing countries like India; therefore, delays affect the overall economy (Doloi et al. 2012). Even, Ahmadi and Shahandashti (2017) showed that construction investments would boost the economy of the state in some U.S. states, while in some other states economy growth would boost the construction market. According to Faridi and El-Sayegh (2006), more than 50% of the construction projects in the United Arab Emirates (UAE) experience delays, making it important to discover the reasons for the delays and find ways to prevent them.

Ahmed et al. (2003) identified ten causes of delays in building constructions in Florida, and grouped them into six broad categories: acts of God, design-related, construction-related, financial/economic, management/administrative, and code-related. They distributed a questionnaire to contractors to discover the types of delays experienced and who was responsible for them.

Yang and Wei (2010) declared that delays in the planning phase cause the subsequent phases (design and construction) to be compressed, putting them behind schedule before they even begin. Furthermore, owing to deep dependency between scheduling and planning of construction project with the local government regulations, all construction parties should be aware of these regulations before beginning construction (Faridi and El-Sayegh, 2016). According to Le-Hoai et al. (2008), design-related problems occur because of mistakes in the design, changes to the design changes, and additional works. As a result of the nature of construction, some design changes, like changes in drawings, specifications, materials, etc., are inevitable, and architects are responsible for them (Faridi and El-Sayegh 2006). Mohamad et al. (2012) investigated the causes of design changes and their effects by surveying three main stakeholders (clients, contractors, and consultants) involved in residential reinforced concrete building projects. They concluded that design changes are most commonly responsible for added costs and delays in the construction phase.

The level of productivity is a significant factor in the duration of a project (Kumaraswamy and Chan, 1995). In 1998, they investigated the causes of delays, based on clients', consultants', and contractors' points of view in Hong Kong. Due to the strong relationship between improving productivity and controlling delays, they examined schedule performance factors. The results were rather inconclusive because of the differences in the perceptions of the stakeholders. All stakeholders, however, believed that an unforeseen ground condition is a significant factor that affects the construction duration. In addition to ground conditions, there are some other factors that cause delays which cannot be attributed to any party, meaning that no one has control over them. Weather condition is one of those uncontrollable factors which is capable of adversely influencing time performance (Faridi and El-Sayegh, 2016).

Le-Hoai et al. 2008 distributed a questionnaire among owners, contractors, and consultants to uncover crucial performance factors during the construction phase. They concluded that most of the factors were related to human errors and inadequate management, and included poor site management and supervision, poor project management assistance, financial difficulties of owner, financial difficulties of contractor, and design changes. According to many studies, construction projects often deviate from the proposed performance because of the owner's and/or contractor's financial issues (Abd El-Razek et al. 2008; Kaliba et al. 2009; Kikwasi, 2013; Le-Hoai et al. 2008). This has a significant effect on running the project smoothly and completing it on time, causing delays in different stages of the project (Le-Hoai et al. 2008, Faridi and El-Sayegh, 2006). With the boom in construction industry, clients mostly prefer to have main contractor in their contract to transfer the time risk to the contractors. Therefore, if contractors do not complete project according to specified time in contract, heavy liquidated damages will be imposed to them based on the contract (Williams, 2003).

Awarding contracts to the lowest bidder is one of the important time and cost performance factors imposed by clients. Most of time, the lowest bids are offered by unqualified contractors or result from the low profit margin requested by contractors due to the competitiveness of the market and/or economic conditions. In both cases, it negatively affects project performance and causes delays (Assaf & Al-Hejji, Frimpong et al. 2003). According to the Lo et al. (2006), an exceptionally low bid causes substandard work, contractor bankruptcy, and/or contract termination, and causes the project to deviate from the initial proposed cost and schedule objectives.

Cost performance factors of construction phase

While most infrastructure projects are subject to cost overruns (Williams et al. 2017), a study by Mahamid and Bruland (2011) concluded that 100% of transportation projects have cost divergence. Approximately 76% of the projects are overestimated, and 23% are underestimated. Flyvbjerg et al. (2002) investigated the importance of underestimation in cost performance of different types of transportation projects. It was concluded that cost underestimation is a global phenomenon that has been a problem for the last 70 years and reflects the significant role of engineering productivity in an effective cost performance. Since engineering productivity, project cost, and changes in construction performance are significantly correlated (Ibbs, 1997; Liao, 2008), Liao et al. (2011) conducted a study to identify the factors that affect engineering productivity. Project size, project type, project priority, and phase involvement were cited as the most significant factors that affect engineering productivity (Liao et al. 2011). Subsequently, they influence the cost performance of a project.

Kometa et al. (1994) examined the cause and effect of the client's organization on the project consultant's performance. The most significant client-related causes are (1) financial stability of client, (2) feasibility of the project, (3) past performance of client, (4) project characteristics, and (5) client's duties. They concluded that a good relationship between the client and the consultant becomes more critical when there is greater competition in the industry. Based on Mahamid and Bruland's (2011) study, consultants in Palestine believe that inadequate time for estimate and incomplete drawings are two significant engineering-related factors that cause the deviation of the actual cost of a project from the planned cost in road construction projects.

However, not all cost overruns can be attributed to engineering performance. Al-Hazim et al. (2017) studied the reasons behind the delays and cost overruns in infrastructure projects in Jordan. They analyzed 40 public infrastructure projects implemented from 2000 to 2008 and concluded that the main causes of delays and cost overruns were related to unforeseen factors, including terrain and weather conditions. In another study by Al-Hazim (2015), terrain conditions were defined as difficulties in reaching the work site, difficulties of the work type, land acquisition issues, delays in relocating utilities, and the lack of civil services near the work site which were not included within the work plan and cost studies. It is important to consider these conditions in the contract to fairly allocate the risk of these unforeseen situations to different parties (Le-Hoai et al. 2008).

2.4. Summery

This chapter features a comprehensive literature review about construction performance and the factors deviating projects from proposed time and cost. More than two hundred performance-related papers were studied from 1971 to 2017 and the findings of each study, along with their utilized methodologies were completely discussed.

Chapter 3

Research Methodology

As it is shown in Figure 3-1, a six-step research methodology was developed in order to identify significant phase-based Key Performance Factors (KPFs) and their Best Practices (BPs) which prevent unnecessary construction cost overrun and schedule delay. First of all, it is tried to define a major problem in construction industry which has not been addressed yet. After defining the problem, an extensive literature review was carried out to collect a vast range of information. The overall framework of the systematic literature review is illustrated in Figure 3-2. Over two hundred journal articles, conference papers, dissertations, and research reports were studied. More than half of all of the papers were journal articles, followed by conference papers; a few of them were dissertations and reports. The identified papers were taken from five main databases: Google Scholar, JSTOR, Scopus, ProQuest, and Science Direct. All of the journal papers were carefully reviewed, and the essential information was extracted from each of them. This information included the name of the journal, the type of industry, the year of the study, the country of origin, identification of factors contributing to the project performance, data collection practices, data analysis techniques, preventive strategies, etc. A number of data analyses were performed after the database was completed. The identified factors were distributed into relevant schedule and cost performance groups of three EPC phases based on the reference papers. Subsequently, all performance factors were classified into different groups. Then the frequency of occurrence of each factor was calculated to find the most frequent factors in the literature. Also, a separate literature review was done to investigate the potential Best Practices (BPs) preventing construction projects from experiencing cost and time overrun.

Based on the results of the literature review, in the third step of the research methodology (Figure 3-1), a detailed and structured survey was developed in three primary sections and distributed among construction practitioners from Construction Industry Institute (CII). Next, the acquired responses were tabulated, and the preliminary data analysis was carried out to descriptively and statistically analyze the cost and schedule performance of the collected projects. In the descriptive analysis, detailed information about the projects' characters provided by respondents were presented, including phase-based baseline and actual cost/schedule of projects. At the same time, different statistical data analyses including two-sample T-test and Kruskal-Wallis were performed to determine the significance level of KPFs and BPs. In the meantime, the data of each KPF and BP were divided into two groups (good and poor performance projects), in order to test whether there is significant difference between the means of two groups. Subsequently, since the respondents' results are consisted of two different data types (continues and Likert-scale data), the author transformed data into a unified format to calculate the weights associated with each of the identified KPFs. Epsilon Squared Effect Size method was applied to weight each KPF in different EPC phases. Based on the results of the effect size method, a weighted and prioritized list of cost and schedule key performance factors for each of the engineering, procurement, and construction phase was developed. KPFs were categorized based on their weights into small, medium and large and the effect size of each of groups was calculated. After identifying the significant BPs in each EPC phase, it is tried to identify the most appropriate BPs for top-ranked phase-based factors. Since our database of BPs were based on the Likert-scale (ordinal data), Kruskal-Wallis test was employed to statistically test the correlation between phase-based BPs and KPFs. As the end, the final research results were interpreted and discussed, and the conclusion was drawn.

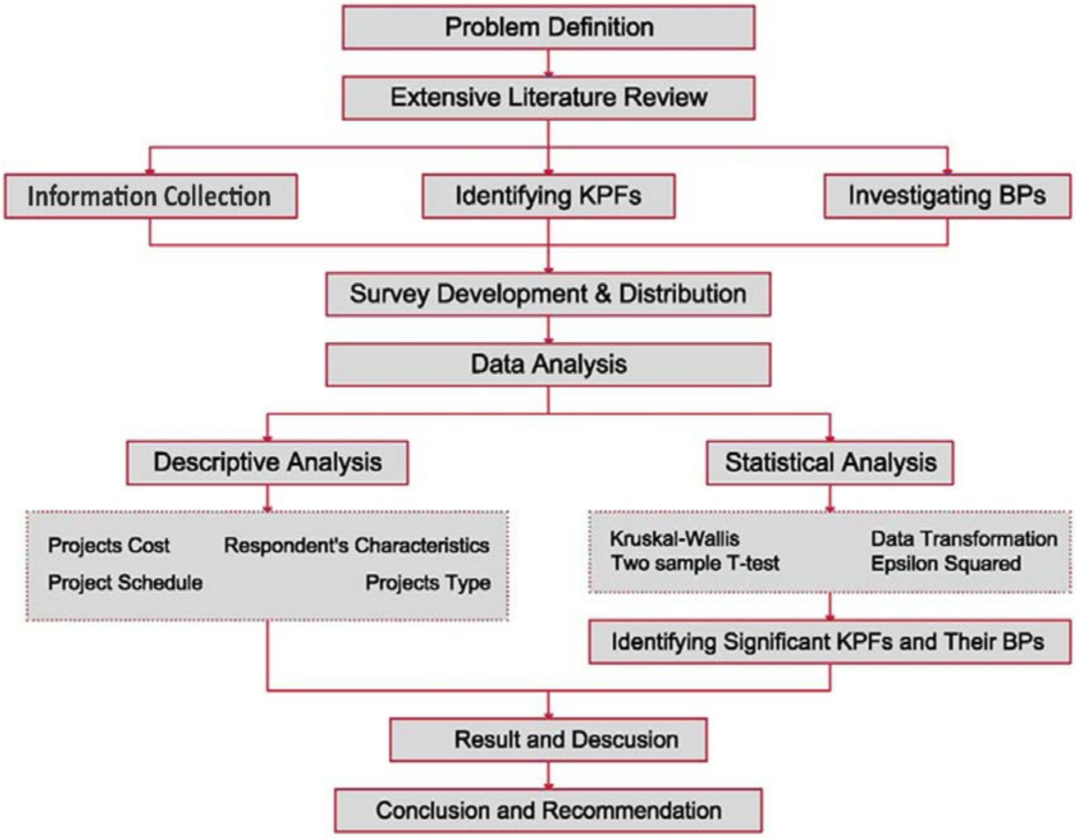

Figure 3-1. Research Methodology

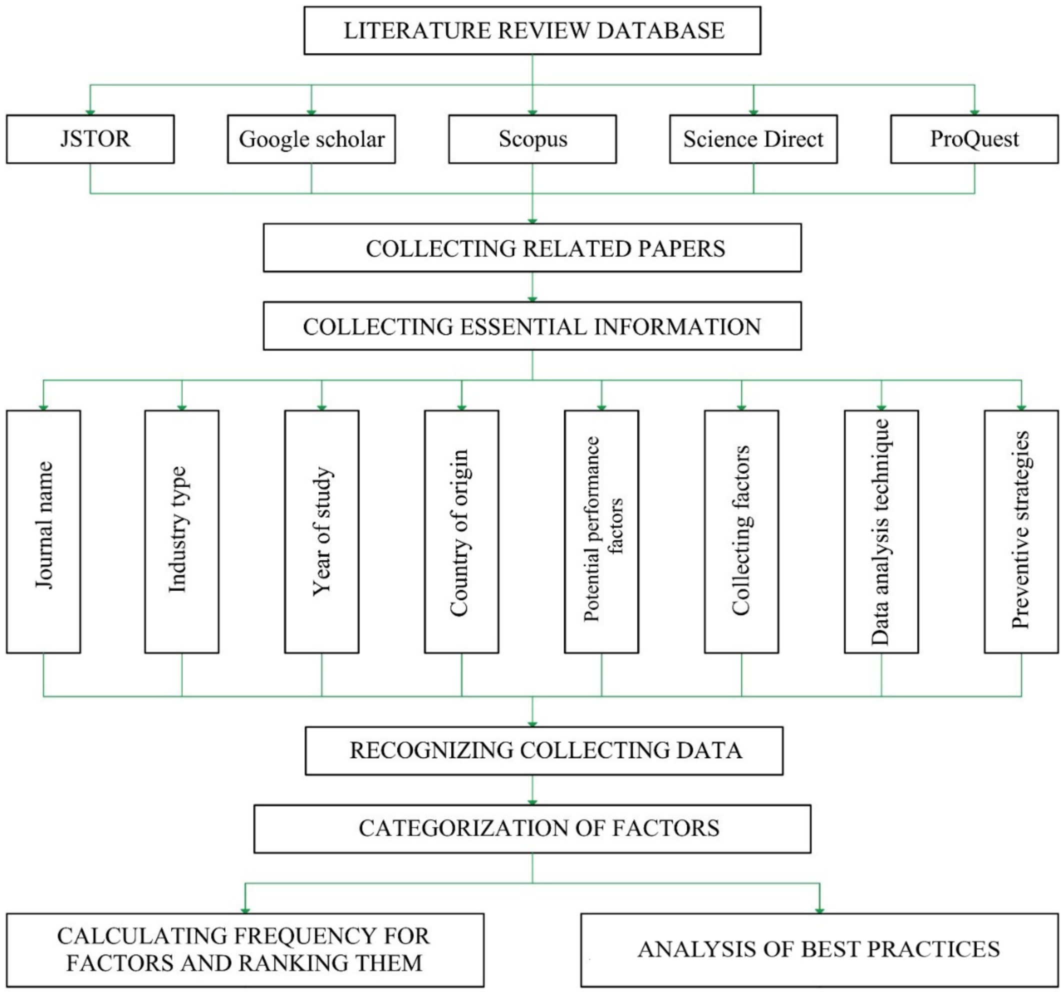

Figure 3-2. Framework of systematic literature review

3.1. Summery

This chapter briefly describes a methodology that the author adopted to first collect potential performance factors and best practices and then statistically test them to find the significant ones by means of a questionnaire.

Chapter 4

Data Collection

Journal Name: Time and cost performance issues in construction have been examined in 32 different journals around the world, and Table 4-1 specifies the distribution of the papers according to their sources. As is indicated in this table, the first five journals, were published on the management journals, with 68% of all papers. The International Journal of Project Management, published in collaboration with the Association for Project Management (APM) and the International Project Management Association (IPMA), ranks first with 30 papers, and accounts for 26% of the total papers. It is followed by the Journal of Construction Engineering and Management and Construction Management & Economics, with 18 and 14 papers, respectively.

Table 4-1. Frequency of Articles by Journals for Cost and Schedule Performance

Journal Title	Frequency	Percentage
International Journal of Project Management	30	26%
Journal of Construction Engineering and Management	18	16%
Construction Management & Economics	14	12%
Journal of Management in Engineering	9	8%
Engineering, Construction and Architectural Management	7	6%
Journal of Construction in Developing Countries	4	3%
Procedia Engineering	3	3%
Cost Engineering-Morgantown	2	2%
Journal of Civil Engineering and Management	2	2%
Journal of Financial Management of Property and Construction	2	2%
KSCE Journal of Civil Engineering	2	2%
International Journal of Emerging Technology and Advanced Engineering	2	2%
Other Journals*	20	17%
Total	115	100%

Industry Type: Figure 4-1 illustrates the distribution of papers according to their project type: building project, transportation project, underground infrastructure project, or general construction project. Among the authors who seek performance factors in the specific industry, the building project has the largest portion of projects, with 30%. Transportation projects and underground infrastructure projects are second and third, representing 24% and 12% of all projects, respectively.

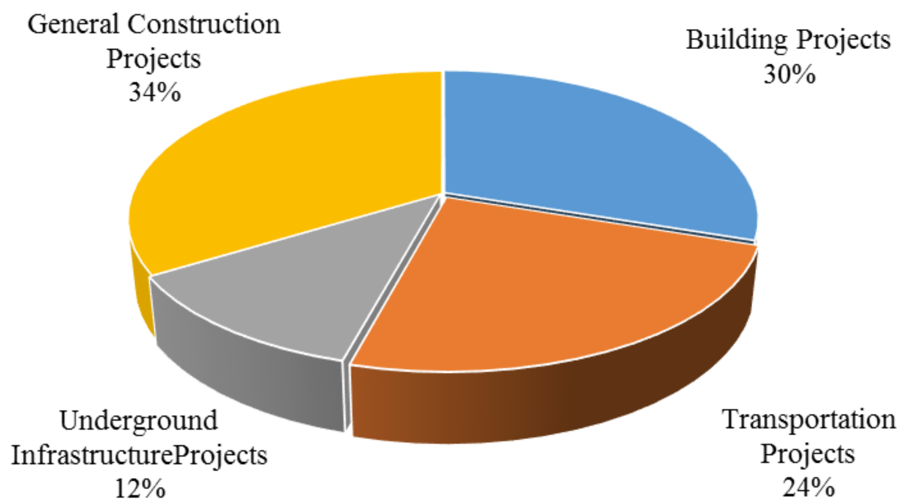

Figure 4-1. Distribution of Papers According to the Type of Projects

Year of Study: As shown in Figure 4-2, the journal articles published during the past 46 years were grouped into five-year segments between 1971 and 2017, and were analyzed. As is shown in this figure, after 1995, there was a sudden increase in the number of scholarly papers written about project performance, which conveys that the issues of delay and cost overruns have become more critical during the last two decades. With 27 journal articles published between 2005 and 2010, this time period received the highest frequency of performance-related studies among all five-year targeted intervals.

According to our research, there were fewer project-controls studies conducted before 1985; however, due to the restricted access to old journal papers, we cannot conclude that this issue was not a matter of controversy among scholars or the construction research community during these years. Since the five-year period of the last group (2015-2017) is in progress, it was not possible to draw any conclusion by comparing this group with the others.

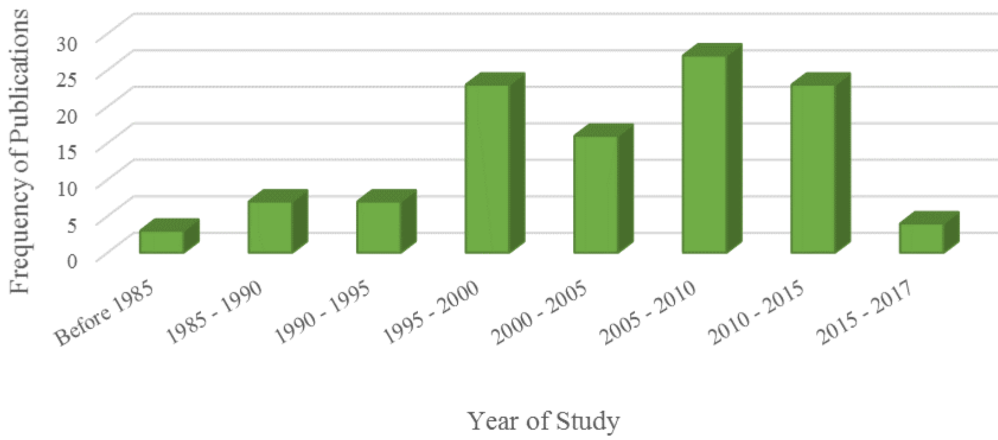

Figure 4-2. Distribution of Journal Articles According to Year of Study

Country of Origin: Figure 4-3 depicts the distribution of papers according to their country of origin. A number of countries in the world identified the causes of cost overruns and delays in the construction industry. As the map shows, time/cost performance issues have been a challenging phenomenon in many developing countries. Long et al. (2004) highlighted that lack of usual occurrence of high performance projects leads scholars to investigate performance issues in these areas. Toor & Ogunlana (2008) also concluded that the causes of delays are similar, regardless of the country in which they occur. A large number of performance-related research papers were initiated in the Middle East and East Asia, representing 29% and 20% of all papers, respectively. Due to the significant role of natural resources in the economy of the Middle East countries, many research efforts have been carried out in this region (Le-Hoai et al. 2008). For our study, Saudi Arabia, Bahrain, Egypt, Iran, Jordan, Kuwait, Lebanon, Palestine, Qatar, Turkey, and the United Arab Emirates are among the countries in the Middle East that took extensive surveys to identify the causes of delays and cost overruns. Africa and North America, with approximately equal portions, placed third (14%) and fourth (13%), respectively. About 30% of all schedule/cost performance studies have been conducted in the United States of America, Saudi Arabia and Nigeria. The United States has the highest portion among all countries, with 12% of all schedule/cost performance studies. Saudi Arabia and Nigeria occupied the following positions with 9% and 8%, respectively.

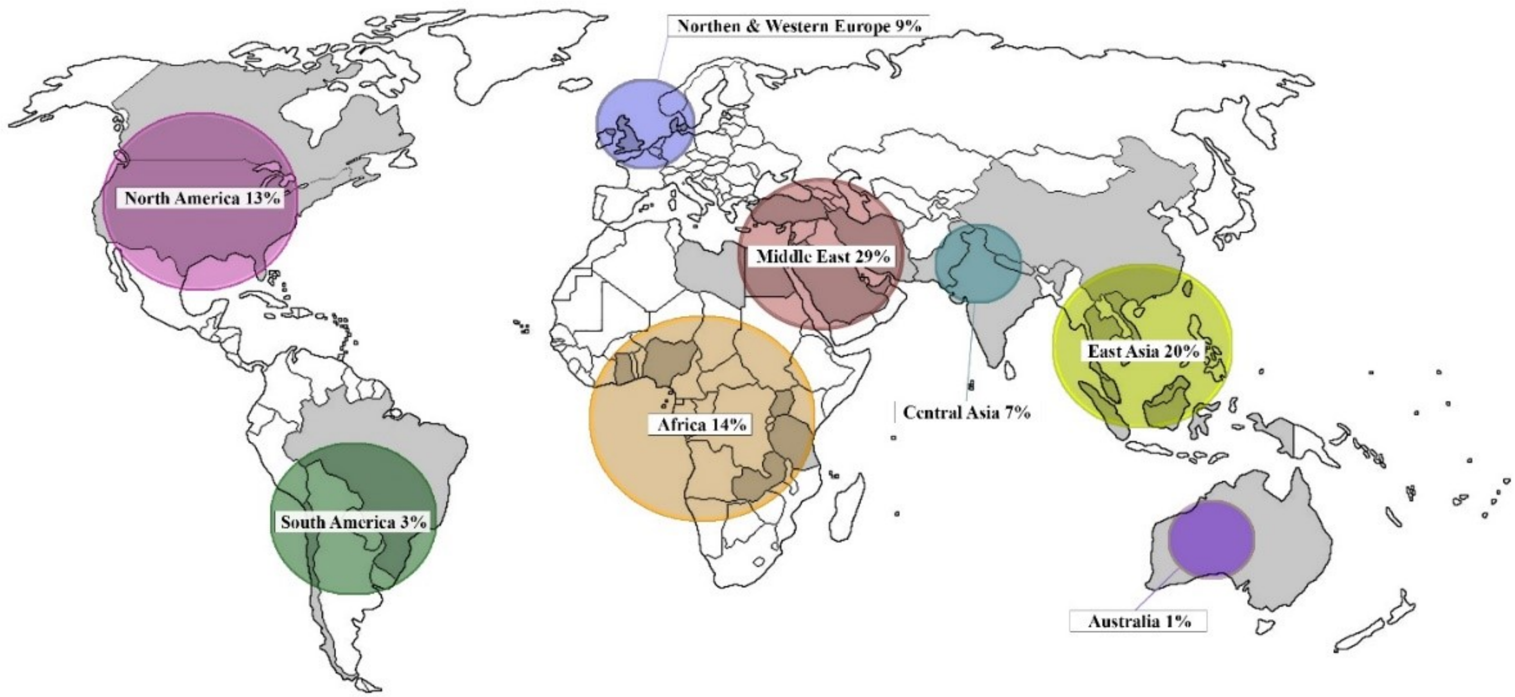

Figure 4-3. Distribution of Papers According To Their Country of Origin

Most research studies examining the issues of time and cost performance adopted the questionnaire approach and performed occasional interviews to prioritize the key causes of delay and cost overrun in construction industry. Assaf et al. (1995) conducted a questionnaire survey based on a review of literature and interview for large building projects in Saudi Arabia. Similarly, many researchers (Alaghbari et al. 2007; Assaf and Al-Hejji 2006; Enshassi et al. 2009; Faridi and El-Sayegh, 2006; Iyer and Jha, 2005; Kaliba et al. 2009; Larsen et al. 2015; Sambasivan and Soon, 2007; Yang and Wei, 2010) framed their research methodology based on conducting questionnaire surveys, but chose different sets of performance factors and data collection practices.

Identification of Performance Causes: The lists of causes of project performance and other information to be included in the questionnaires were as numerous and varied as the authors themselves. These various lists were usually acquired by conducting pilot surveys, case studies, interviews, and literature reviews. The distribution of papers according to their selected data collection practices is shown in Figure 4-4. It should be noted that in most studies, a combination of practices was used to collect required data. However, looking at the practices individually revealed that reviewing literature is the most common practice for data collection and ranks first, with 38% of all practices. Interviews are the next most common practice and occur in 36% of all practices. Case studies and pilot studies both occupy third place, with just 13% of all practices.

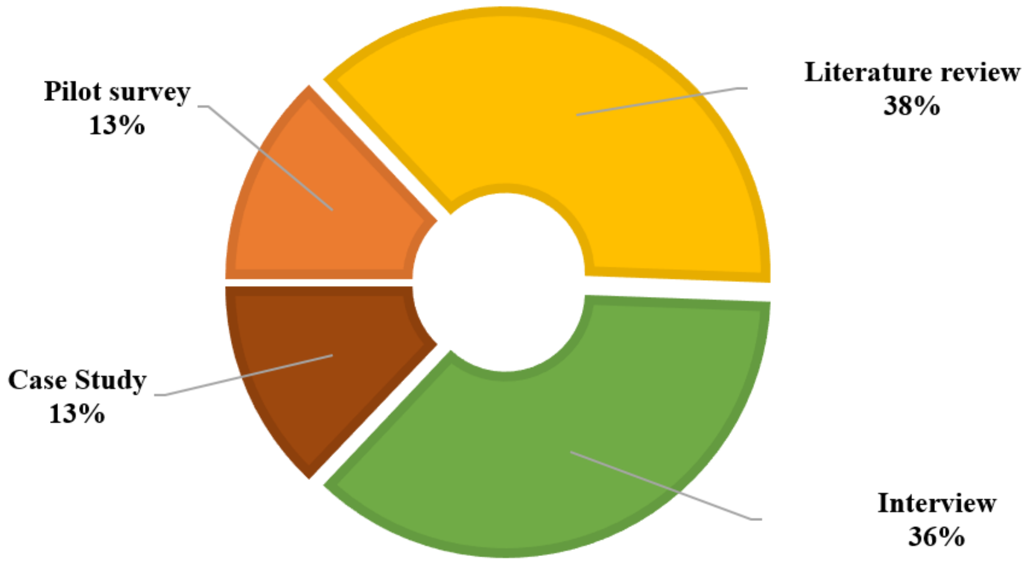

Figure 4-4. Identification of Performance Causes

Questionnaire Design: Different approaches were adopted for designing the questionnaires for data analysis. Alhomidan (2013) developed a questionnaire from the contractor's perspective to investigate the key cost overrun factors in Saudi Arabia. The questionnaire was based on 41 factors, identified according to a detailed literature review, that were categorized into six groups. The questionnaire was distributed among contracting firms to evaluate the severity and frequency of cost overruns.

Fallahnejad (2013) conducted research in two stages to identify the causes of delays in Iran's gas pipeline projects. The first stage included reviews of literature and project documents executed from 2004 to 2011. In the second stage, ten interviews were conducted with project managers, domestic procurement managers, international procurement managers, contract managers, financial managers, and legal experts to modify and expand the initial list. Their questionnaire was designed based on the findings of their two-stage research and included a section for respondents to provide their personal and organizational information.

Data Analysis Techniques: Different techniques were used to evaluate the data procured from the questionnaires, including the frequency index (F.I.), severity index (S.I.), important index (II), relative importance index (RII.), mean score (M.S), cost performance index (C.P.I), regression, average relative weight, weighted average (WA), rank correlation coefficient, etc. Figure 4-5 indicates the distribution of utilized data analysis techniques in the identified journal papers. RII ranked first among the analysis techniques with 26%, followed by the severity index. II and M.S were the third most common techniques, equaling 13% of all utilized techniques.

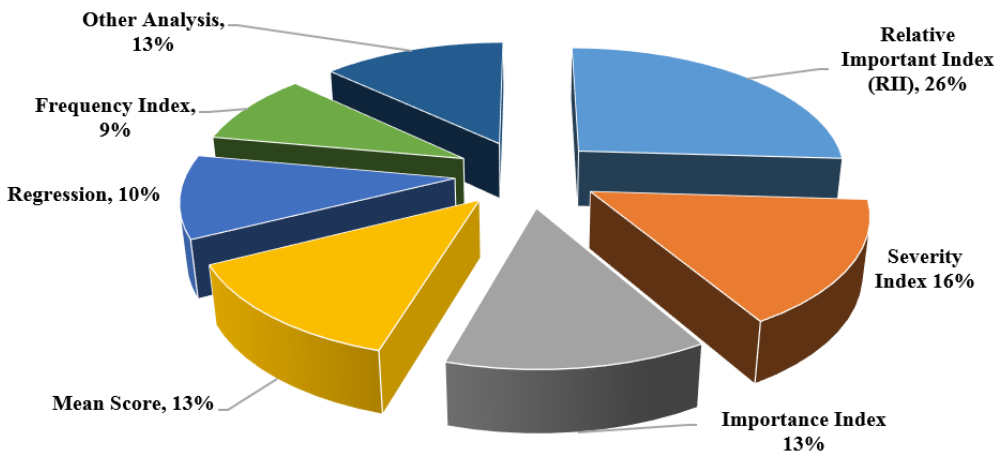

Figure 4-5. Distribution of Papers According to the Technique of Data Analysis

Based on Alinaitwe's (2013) study, a questionnaire was prepared to assess the frequency, severity, and importance of each cost and time performance factor. The pilot questionnaire was tweaked to improve its quality and reliability, and the finalized questionnaire was sent out to clients and contractors. The respondents were asked to indicate the frequency and severity of each of the identified factors, using a 4-point Likert scale ranging from 0 (never happened and no effect) to 4 (always happened and very severe). According to Asiedu & Alfen (2016), the frequency (F.I.) and severity indices (S.I.) expressed the frequency of occurrence and the magnitude of the variables, respectively. Literature often used the relative importance index (RII.), which is based on the S.I and F.I, to identify the most crucial variables (Assaf and Al-Hejji 2006; Asiedu & Alfen 2016; Chan and Kumaraswamy 1997; Doloi, 2012; Le-Hoai et al. 2008; Megha & Rajiv 2013; Sambasivan and Soon, 2007). It is computed utilizing following equations:

S.I. (%)=$\Sigma(\psi_i \Phi_i / \lambda \Omega) \times 100\%$

F.I. (%)=$\Sigma(\psi_i \Phi_i / \lambda \Omega) \times 100\%$

RII. (%)= $S.I.(\%) \times F.I.(\%) \times 100$

Where:

Φ_i = is the frequency of the responses of the i^{th} rank

λ = is the highest weight

Ω = is the total number of responses

ψ_i = Is the constant expressing the weights assigned to each of the factors by the respondents of the i^{th} rank

The trends of utilization of data analysis techniques that were published in papers from 1971 to 2017 were studied, and the results are reported in 5-year periods in Figure 4-6. Due to the small number of relevant papers published before 1990, they were not considered in the trend analysis of this study. Furthermore, due to the incomplete (2-year period) of the last group (2015-2017), its results were combined with those of the period from 2010-2015. As is shown in the figure, despite a constant trend from 1995 to 2005 for utilization of RIIs, this technique became more popular during the last decade. Other techniques were used less frequently, and their utilization trends fluctuated during that time.

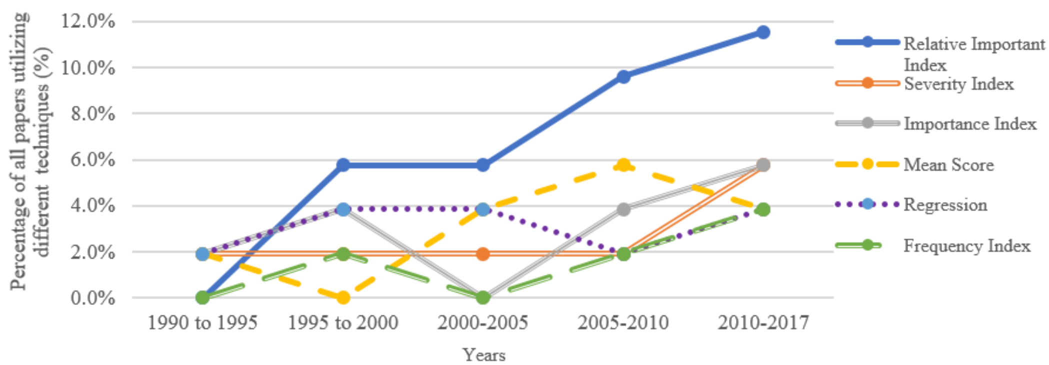

Figure 4-6. Trend of Utilization of Data Analysis Techniques in Published Paper

Identification and Categorization of Factors: All of the cost and time performance factors in the construction industry were identified from over two hundred papers and were classified into the following twelve groups: change, consultant, client, labor, contractor, material, equipment, external, project, management, planning-scheduling-estimating (P-S-E), and contract. According to the original papers, each factor was distributed to the related EPC phases; then, they were separated into categories of cost performance and schedule performance in each EPC phase. Ultimately, 121 performance factors were identified and presented in Appendix A. The frequency of occurrence of each factor was calculated from literature to find most frequent performance factors.

Table 4-2 presents the definition of each group, along with the phases in which each category has potential KPFs. Notably, since client and consultant have a number of factors in common, it is decided to combine both groups and put them in a single group.

Table 4-2. Classification of Performance Factors and Their Definitions

Group	Description	ENG.		PRO.		CON.	
		SP	CP	SP	CP	SP	CP
Change	Change includes any omissions, errors, addition and change of scope	√	√			√	√
Management	Management factors include adequate communication, control mechanisms, feedback capabilities, troubleshooting, coordination effectiveness, decision making effectiveness, monitoring and related previous management experience	√	√	√	√	√	√
Contract	Contract includes problems involving the contractual relationship among the various parties involved in a project and all factors which can be attributed to the contract documents	√	√			√	√
Client & Consultant	The client-related factors concerned with client characteristics, client type and experience, knowledge of construction project organization, project financing, client confidence in the construction team, well-defined scope Consultant-related factors consist of design team experience, project design complexity, and mistakes/delays in producing design documents	√	√			√	√
P.S.E	P.S.E consists any problems in planning, scheduling and cost estimating	√	√			√	√
Contractor	Contractor-related includes contractor experience, supervision and involvement of subcontracting, contractor's cash flow and effectiveness of cost control system			√	√	√	√
Labor	Manpower includes shortages of labor, labor skill, and nationalities of laborers	√	√	√	√	√	√
Project	Project-related factors can be attributed to general characteristics of project including type of project, nature of project, number of floors of the project, complexity of project, and size of project.	√	√			√	√
Material	Material-related includes shortages, materials changes, delivery, damage, and manufacturing of materials.			√	√	√	√
Equipment	Equipment-related includes failure, shortage, and delivery of the equipment, or the productivity or skill of the operator of the equipment			√	√	√	√
External	All external influences on the construction process including social, political, economic, physical, industrial and technical systems			√	√	√	√

According to this table, all groups have at least one KPF in construction phase, while procurement phase covers the smaller number of categories compared to that of other two groups. However, it does not necessarily mean that the effect of procurement and engineering phases on overall construction performance is the least. Moreover, the existence of factors from “management” and “labor” groups in all EPC phases expresses the vital role of these two groups from the very beginning to the substantial completion of project.

Engineering Phase Factor: All of the performance factors in the engineering phase were identified in this research, and were ranked on the basis of how frequently they occurred in literature. These factors were categorized and are shown in Table 4-3. The frequency of performance factors in the engineering phase is less than that of subsequent phases, primarily because of the lack of attention paid to the engineering phase performance by construction researchers. It was found that design change is the main reason for postponing the time schedule, increasing the cost of the engineering phase. Slowness in making decisions and delays in the approval stage ranked second. Out of 13 important causes of delays in the engineering phase, 7 fall under the category of consultant-related and client-related, which implies that these two stakeholders are most responsible for delays in the initial phase of construction projects. Poor communication between stakeholders is another KPF affecting time performance negatively (Kamalirad & Kermanshachi, 2017) and causing cost overruns during the engineering phase. After design change, this and the project size have the highest effects on the cost performance of the engineering phase.

Table 4-3. Cost and Schedule Performance Factors in Engineering Phase

Category	Key Performance Factors	F*	R**
Schedule Performance Factors			
Change	Design change	13	1
Management	Slowness in making decisions	8	2
Client	Delay in approval stage	8	2
Management	Poor communication between different stakeholders	5	3
Consultant	Design error	4	4
Client	Poor scope definition	4	4
Client	Incomplete documents	3	5
Client	Client Type in terms of experience, knowledge and Past performance	3	5
Management	Inadequate management	3	5
Consultant	Late incorporation of emerging technologies (software)	3	5
Consultant	Designer experience	3	5
Planning-Scheduling-Estimating	Deficiencies in planning and scheduling stage	3	5
Labor	Labor shortage (staff)	3	5
Cost Performance Factors			
Change	Design change	7	1
Management	Poor communication between different stakeholders	4	2
Project	Project size	4	2
Management	Inadequate management	2	3
Consultant	Design error	2	3
Client	Payment delay by client	2	3

* Frequency
** Rank

Procurement Phase Factor: Due to unique characteristics of the procurement phase, few factors in this phase are in common with other phases (Table 4-4). The availability of resources (materials, labor, and equipment) plays an important role in time and cost during the procurement phase. Among these resources, material shortage has the highest frequency of occurrence, with 16 references for schedule performance and 9 references for cost performance. Price fluctuation is the most significant factor that affects the construction market and has been referenced 14 times in literature. Poor economic conditions and material shortages are the second most common causes of cost overruns in the procurement phase. Most of the KPFs in the procurement phase are categorized in material-related and external groups.

Table 4-4. Cost and Schedule Performance Factors in Procurement Phase

Category	Key Performance Factors	F*	R**
	Schedule Performance Factors		
Material	Shortage of Construction Material	16	1
Equipment	Equipment Shortage (Machinery and its parts)	14	2
Labor	Shortage of site labor	13	3
Common (Material-Equipment)	Late Delivery of material and equipment	10	4
Material	Material Imported internationally	7	5
External	Price fluctuations	7	5
Material	Quality of raw materials	6	6
Equipment	Low equipment productivity (Quality, Age, production)	6	6
Labor	Shortage of technical staff	6	6
External	Poor economic conditions (exchange rate, inflation rate, Interest rate, etc.)	6	6
External	Transportation difficulties	5	7
External	Market conditions	4	8
Labor	Labor Supply	3	9
	Cost Performance Factors		
External	Price fluctuations	14	1
External	Poor economic conditions (exchange rate, inflation rate, Interest rate, etc.)	9	2
Material	Shortage of Construction Material	9	2
Labor	Shortage of site labor	8	3
External	Market conditions	6	4
Material	Material Imported internationally	5	5
External	Transportation Difficulties	3	6
Equipment	Equipment Shortage (Machinery and its parts)	3	6

* Frequency
** Rank

Construction Phase Factor: Table 4-5 shows the most frequent schedule/cost performance factors in the construction phase. Since a large number of construction researchers concentrated on the performance of this phase, the diversity and the frequency of factors in this phase is higher compared to other phases.

Table 4-5. Cost and Schedule Performance Factors in Construction Phase

Category	Factors	F*	R**
Schedule Performance Factors			
Change	Design change	28	1
Management	Poor site management and supervision	18	2
External	Severe weather condition	17	3
Client	Financial issues by client	17	3
Management	Delay in decision making process	14	4
External	Unforeseen condition (natural disaster…)	14	4
Planning and scheduling	Deficiencies in planning and scheduling	14	4
Consultant	Delay in performing inspection and testing	13	5
Contractor	Construction mistakes and defective work	13	5
External	Geological Conditions/ Terrain Condition	12	6
Management	Lack of communication and coordination between the stakeholders involved in construction	12	6
Contractor	Contractors' financial difficulties	12	6
Consultant	Design error	11	7
Client	Funding delay	10	8
Contract	Aggressive schedule for project construction/ Unrealistic contract durations imposed by client	10	8
Cost Performance Factors			
Change	Design change	14	1
External	Severe weather Condition	11	2
External	Laws and regulations	10	3
Consultant	Inaccuracy and deficiencies in cost estimates	10	3
Management	Poor management by contractor	9	4
External	Geological Conditions/ Terrain Condition	8	5
Finance	Schedule delay	8	5
Consultant	Delay in approval stage	7	6
Management	Contract management	7	6
Project	Project size	7	6

* Frequency
** Rank

According to Table 4-5, design change is the primary cause of changes in the estimated time and cost of the construction phase, with 28 and 14 citations, respectively, followed by poor site management and supervision in the schedule list. “Severe weather conditions” was cited as one of the most common factors causing delays and cost increases during the construction. It is identified as the second most frequent factors increasing the cost of construction phase. However, “Severe weather condition”, along with “Financial issues by client”, both place in the third position among the schedule KPFs in construction phase. Laws and regulations and inaccuracy and deficiencies in cost estimates ranked third in the cost KPFs list in the construction phase.

The distribution of the top ten KPFs in groups according to their related EPC phases and related time/cost performance is shown in Figure 4-7. Large portions of KPFs were distributed into the management group, indicating the importance of this group, especially in the engineering and construction phases. The results of the questionnaire administered by Le-Hoai et al. (2008) also revealed that most of the delay factors are human and/or management related. External and consultant groups place in second and third positions, respectively, with external having ten factors and consultant having seven. All KPFs in the external group are classified into procurement and construction phases and mostly related to the economic conditions, governmental issues, and unanticipated situations, meaning that very few of the three main stakeholders can be considered as the main causes of these KPFs. The most frequent factors in the external group are price fluctuations, market conditions, laws and regulations, poor terrain conditions, and severe weather. As is seen in Figure 4-7, client and material groups occupy the subsequent places in the order given. It should be noted that one of the twelve groups (contract group) does not have any factors among the top ten ranking factors of each EPC phase.

It should be noted that researchers mostly devoted their attention and time to investigating performance factors in the construction and procurement phases, and the procurement phase was often considered a part of the construction phase, rather than a separate phase. Moreover, despite the important role of the engineering phase in construction performance, few studies were targeted specifically at identifying the performance factors affecting this phase.

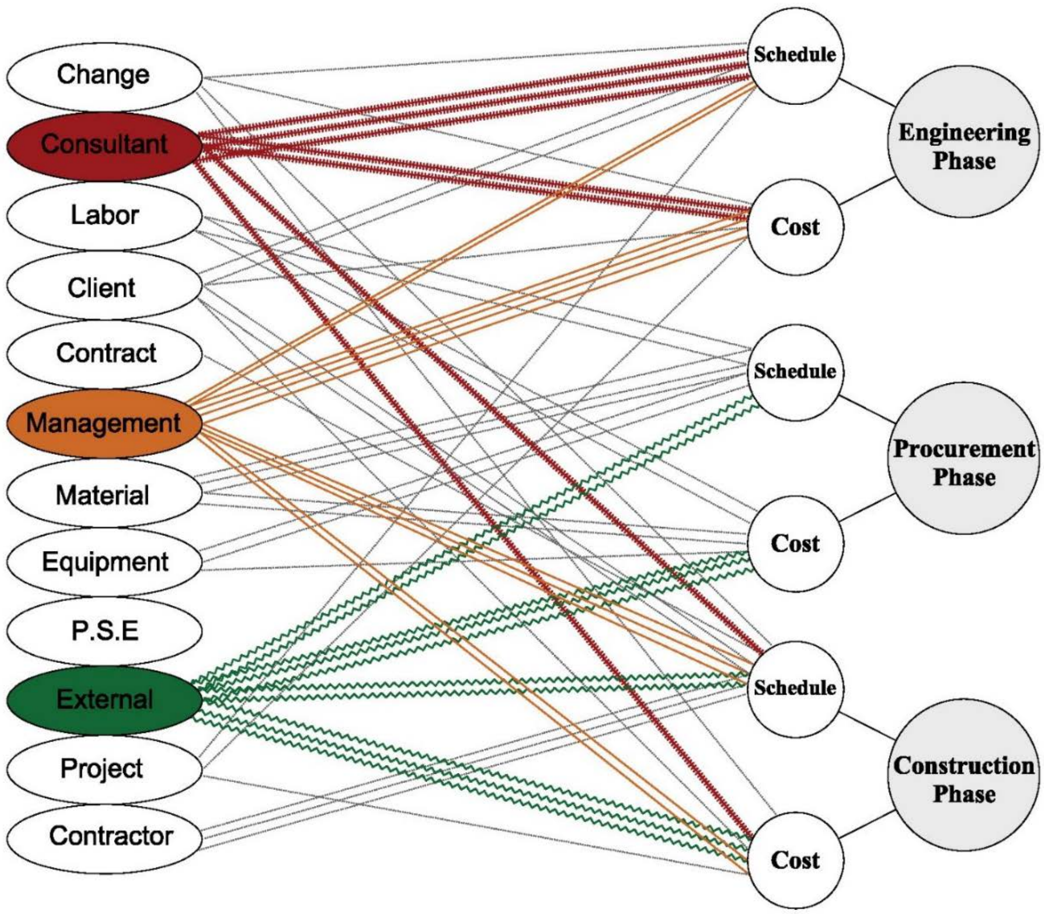

Figure 4-7. Distribution of Top Ten KPFs in Different Design-Based Performance Groups

Many researchers helped the construction research community by identifying the most significant corrective actions or preventive measures for ineffective schedule/cost performance (Mohamad et al. 2012, Kuprenas 2003, Assaf and Al-Hejji 2006). Following the investigation of the top five leading causes of schedule and cost performance overruns, Olawale and Sun (2010), reported 90 mitigating measures caused by design changes, risks/uncertainties, inaccurate estimation of project time/duration, complexities, and non-performance of subcontractors. Although several studies highlighted the beneficial effects of best practices on overall project performances, Lee et al. (2005) emphasized the influence of practices on time and cost performance specifically, citing the leading practices affecting both cost and schedule performance as pre-project planning, project change management, and design/ information technology practices. The other three strategies, team building, constructability, and zero accident strategies, were cited as being less significant than the first three strategies. Even though constructability is a schedule-and-cost-beneficial strategy, team building and zero accident also have effects on cost and schedule performance. By means of descriptive statistics and ranking analysis, Ali and Kamaruzzaman (2010) ranked the proposed list of strategies that resulted from their questionnaire. They realized that overruns in cost can be controlled by having proper project financing. Since delays and cost overruns in groundwater construction projects often result from poor resource management, effective project planning, controlling, and monitoring should be performed from the planning stage to the implementation and management stages (Frimpong et al. 2003).

Ling et al. (2009) examined the best project management (PM) strategies in nine different PM areas which were adopted by Singaporean AEC firms in Chinese international construction projects. The top three strategies were: offer high quality responses towards perceived variations, control technology transfer risks effectively, and conform closely to contract requirements. Ling et al.’s (2009) study indicated a significant positive correlation between accept, approve and commit to the schedule early, control language barrier risk effectively, and better schedule performance. Language barriers may cause poor integration and communication among construction participants, resulting in construction projects facing reworks, cost increases, and delays (Gunhan & Arditi, 2005).

Kermanshachi et al. (2016) investigated and collected strategies which manage project complexity and improve project cost performance for both contractors and clients. Safapour et al. (2017) explored and assessed utilization of five important best practices to reduce the time schedule and save the cost of construction projects for client entity. These five best practices include team building, alignment, change management, front end planning and partnering.

Table 4-6 illustrates the phase-based preventative strategies and responsibilities of the entity in charge to have an optimized cost/schedule performance. These strategies either control the delays and cost overruns or minimize their effects on the project. According to this table, clients and consultants are critical stakeholders who affect the performance of the engineering phase. Similarly, the procurement phase would have better schedule/ cost performance if contractors and external groups (governments, suppliers, etc.) adopted appropriate financial, economic, and educational policies. However, improvement in the construction phase performance is not restricted to one or a few specific stakeholders. All stakeholders should take an active role in reducing potential construction risks and enhance construction cost and schedule performance.

According to Table 4-6, potential risks of delays and cost overruns in the engineering phase can be minimized when consultants allocate adequate resources to meet the client's requirements and improve the quality of communication between members of the design team. Clients should devote enough time and money to conducting preliminary studies to avoid any delays in the decision-making process. The performance of the procurement phase can be highly improved by competent contractor's management: by applying appropriate financial techniques, selecting qualified local vendors, and providing educational programs for beginners. Preventive performance strategies in the first two EPC phases often affect construction performance by implementing constructability during the design phase and minimizing the lapse in management of material and human resources in procurement phase. Strong, effective information flow and management during the implementation stage can result in better time/cost performance in the construction phase.

Table 4-6. Preventive Strategies to Minimize/Control Time and Cost Performance Issue

Responsible Entity	Preventive Strategies
Consultant	Devoting sufficient time to develop client's concept correctly at the design phase and to meet all the requirements of the work [Mohamad et al. 2012]
	Organizing meetings between design team and submitting written progress report of initial phase at least twice per month [Kuprenas, 2003]
	Design/information technology practice use [Lee et al. 2005]
	Implementing constructability during the design phase [Kometa et al. 1994], [Lee et al. 2005]
Client	Considering financial motivation for designers to have a better schedule performance [Kometa et al. 1994]
	Allocating adequate time and money for feasibility studies and site investigations to avoid unanticipated situations at the beginning of planning stage [Mohamad et al. 2012]
	Pre-project planning: Providing sufficient information for owner to take a right decision and minimize potential risks and lead project to success [Lee et al. 2005]
	Avoid slowness in review and approval stage of design documents by clients [Assaf & Al-Hejji, 2006]
	Proper funding level should be defined at planning stage to be payed to contractor regularly according to the amount of work done [Frimpong et al. 2003]
	Process selection of a good contractor should be taken place and important criteria like work experience and reputation should be considered [Lo et al. 2006]
	Make sure that all project requirements are included in bid price and reject lowest bids that have not considered involved risk [Lo et al. 2006]

Table 4-6 (Cont'd)

Contractor	Taking the advantages of blanket purchase agreement, also known as call-off order, to be ahead of schedule [Alarcon, 1997]
	Selecting local vendors to shorten transport distance [Alarcon, 1997]
	Zero accident techniques: Implementing trainings include site-specific safety programs to create a safe job site and prevent all accidents [Lee et al. 2005]
	Taking an advantage of qualified management to meet the project's plan requirements during the construction phase [Al-Hazim et al. 2017]
	Minimizing the lapse in management of material and human resources to mitigate the high cost of the project [Okpala & Aniekwu, 1988]
	Performing continuous work-training programs for personnel in the industry to update their knowledge and be familiar with project management techniques and processes [Frimpong et al. 2003]
	Effective material procurement should be executed to improve procurement performance and avoid potential supply delay [Frimpong et al. 2003]
Consultant, Client	A clear and complete scope definition should be considered to minimize potential variations [Lo et al. 2006]
	Managing design process properly and making decisions on time to control the delay and cost overrun of the project [Ahmed et al. 2003]
Consultant, Client, Contractor	Team Building: Building and developing share goals, independence, trust and commitment and accountability among team members to improve problem-solving skills of team members [Lee et al. 2005]
	Settling information flow or interaction channel to address problems during implementation stage [Le-Hoai et al. 2008]
	Have an independent commission for evaluation of the performance on important construction projects to save resource and increase the total efficiency by all stake holders [Toor & Ogunlana, 2008]
	Project change management: incorporating a balanced change culture of recognition, planning and evaluation of project changes in an organization to effectively manage project changes [Lee et al. 2005]
External	Increasing labor's wage and providing training scheme for beginners to address the labor and skill shortage problem [Ho, 2016]
	Importing the required goods and qualified services [Ogunlana et al. 1996], [Ho, 2016]

4.1. Summery

Chapter 4 descriptively analyzed the information found from an extensive literature review and presented them in different manners. In other words, this chapter compares different project types, countries of origin, data analysis techniques and research methodologies that previous studies utilized in construction industry.

Furthermore, A list of schedule and cost factors in each EPC phase was presented, and all factors were ranked based on the frequency of occurrence in the literature. Moreover, it is tried to study and collect best practices that is found by previous researchers and provide them in this chapter. Apart from performance factors and their best practices, all other basic and essential information assisting the author to conduct this research was carefully examined and the results were presented in this chapter.

Chapter 5

Survey Development

Following the categorization of identified factors, the frequency of occurrence of each factor in the literature was calculated in order to prioritize them in each EPC phase. As a variety of factors had the same frequency, 121 performance factors have been ranked ranging from 1 to 18 based on their frequency. A detailed survey was developed on the basis of acquired KPFs to assess the significance level and effect size of each factors. Since the number of KPFs with low frequency (1, 2 and 3) was so large, it was decided to exclude those factors having frequency with less or equal to 3 and narrow down our list. In general, this questionnaire was designed in three sections; (1) Project general description (2) Key Performance Factors (KPFs) (3) Best practices preventing construction projects from having cost overrun and delay. Herein, a question was designed for each KPF in the survey to ask respondents about the impact of factors on the EPC cost and schedule performance. Section 1, project general description, includes 20 questions asking about the general information and project characteristics of the examined projects such as size, duration, contract, type, delivery method etc. of projects. Section 2, included questions which were used to collect data for analyzing KPFs. A list of the most significant factors affecting each of EPC phases was prepared from the literature review and provided in this section. Overall, 38 significant KPFs which contribute more to the phase-based delay and cost overrun in construction projects form the framework of this section. Section 3, Best Practice Implementation, consisted of 13 questions provided information about the level of best practice implementation for each project. Overall, 71 questions were provided for all three sections in two formats. Figure

5-1 depicted two different types of question designed in the questionnaire. As it is shown, the collected responses were in the forms of continuous number or ordinal Likert scale.

Likert scale questions: Likert-type scale is a kind of rating score utilized to specify level of respondents' feelings on a symmetric point scale for a series of statements. Five and seven point-scale are the most widely used approaches to scale responses in survey studies. Questions in this study were designed based on Likert scale with 7 points to assess level of agreement/disagreement of respondents. For instance, question 49 in Figure 5-1 provides a typical example to measure respondents' agreement with a variety of statements. Each of 7 points indicates different degrees of relationship between KPFs and construction performance. Due to this matter, the definition of points was provided in the question for more clarification.

Numerical questions: These questions require respondents to enter a continuous number for the answer. For example, question 40 in Figure 5-1 illustrates a good example of numerical question, as respondents should provide a value for the number of funding phases they have had from concept to project completion.

When the survey was fully developed, a pilot-survey was distributed among four industry-experienced practitioners to validate the clarity of each question. As a result, an extensive definition was added to some questions for more clarification. Eventually, the finalized questionnaire was distributed among potential Construction Industry Institute (CII) members mostly working as project managers in heavy industrial projects comprising oil/gas exploration, mining,etc. via an online platform. They were asked to select two projects completed in the last three years and fill the questionnaire based on the requested information. The intent of the questionnaire was to evaluate the different KPFs based on the responses between poor project performance and good project performance in terms of time and cost. Differences between two groups should be statistically significant to assert that the KPF is a true reflection of project performance key factor.

49- Was the process for defining the project's scope understood during the selection of designers and contractors?

Extremely clear		Somewhat Ambiguous			Completely Ambiguous	
1	2	3	4	5	6	7
☐	☐	☐	☐	☐	☐	☐

40- What was the number of funding phases (gates) from concept to project completion?

Number:____________

Figure 5-1. Sample Questions in the Survey

5.1. Summery

All the results found in the literature review section, were utilized to design a detailed questionnaire and distribute to the potential CII members who works as project managers in the mostly heavy industrial projects. This survey is divided into three sections and asked about general information of selected projects by respondents, key performance factors and best practices respectively.

Chapter 6

Data Analysis and Result

6.1. Preliminary Data Analysis

All in all, 44 completed survey responses were collected. Most of the respondents had more than 15-year experience of handling construction projects and the significant number of them were project manager. The detailed information about the survey responses and experience level of the respondents could be found in Appendix C and Appendix D. Since highly experienced construction practitioners filled the survey, it can be concluded that the results of the questionnaire were highly reliable.

The average budgeted cost of the studied projects was $120 million, ranging from $0.4 million to $575 million. Moreover, the final duration of these projects varied from 8 months to 54 months with the average duration of approximately 24 months. Figure 6-1 illustrates the baseline cost and schedule of the collected data using box-plot. These box-plots demonstrate range, maximum, minimum and median values for the baseline cost and schedule of the studied projects in each EPC phase. As it is illustrated, the average value of construction and procurement phases was almost the same with approximately $60 million. This average for engineering phase was about one ninth of other groups with around $7 million. On the other hand, as it is predicted, the average time scheduled to complete construction phase of industrial projects was higher than other phases, with 16 months. However, engineering and procurement phase took 10 months on average to reach completion.

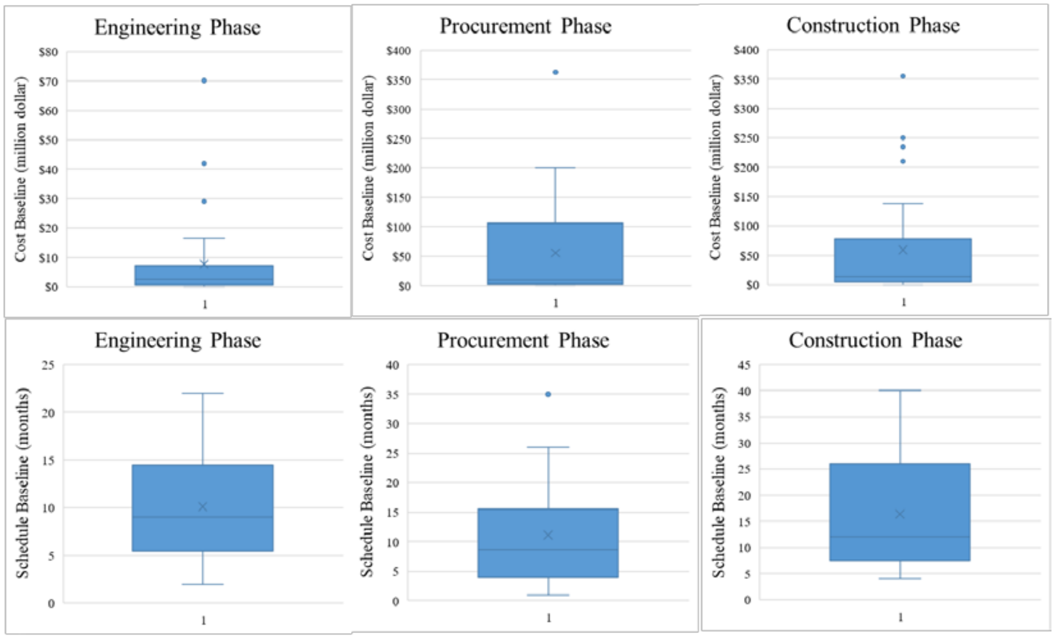

Figure 6-1. Box-plot of Baseline Cost and Schedule of Examined Projects in the Survey

According to Kermanshachi (2016), the common magnitude of deviation in performance for construction performance is 5% to 10% of the budgeted performance. To be conservative, projects with less than 10% performance deviation is considered as good performance projects in this research, while poor performance projects deviate from their proposed performance more than 10%. Consequently, out of 44 projects, 19 projects were good performance projects and the remaining projects (25 projects) were categorized in the poor performance projects. According to the Figure 6-2, the budgeted cost of good performance projects ranges from $0.425 million to $550 million, while the size of poor performance projects varies from $0.639 million to $575 million. In the meantime, the average budgeted cost for the former is $137 million and for the latter is $110 million. These statistics indicate that costlier projects have better performance, compared to the smaller projects. By looking at the actual costs, it was determined thatthere are increases of 6% and 11% in the average costs of good and poor performance projects respectively. Regarding schedule performance, the total baseline schedule for the heavy industrial projects ranged from 8 months to 54 months. Looking at the figure more attentively, it was revealed that projects with longer duration faced higher delay in comparison with projects with shorter duration, as the averages for good and poor performance projects are 22 and 25 months respectively. Moreover, as it is seen in Figure 6-2, the actual schedule averages for good and poor performance projects are 24 and 31 months, showing about 9% and 24% increase in time schedule respectively.

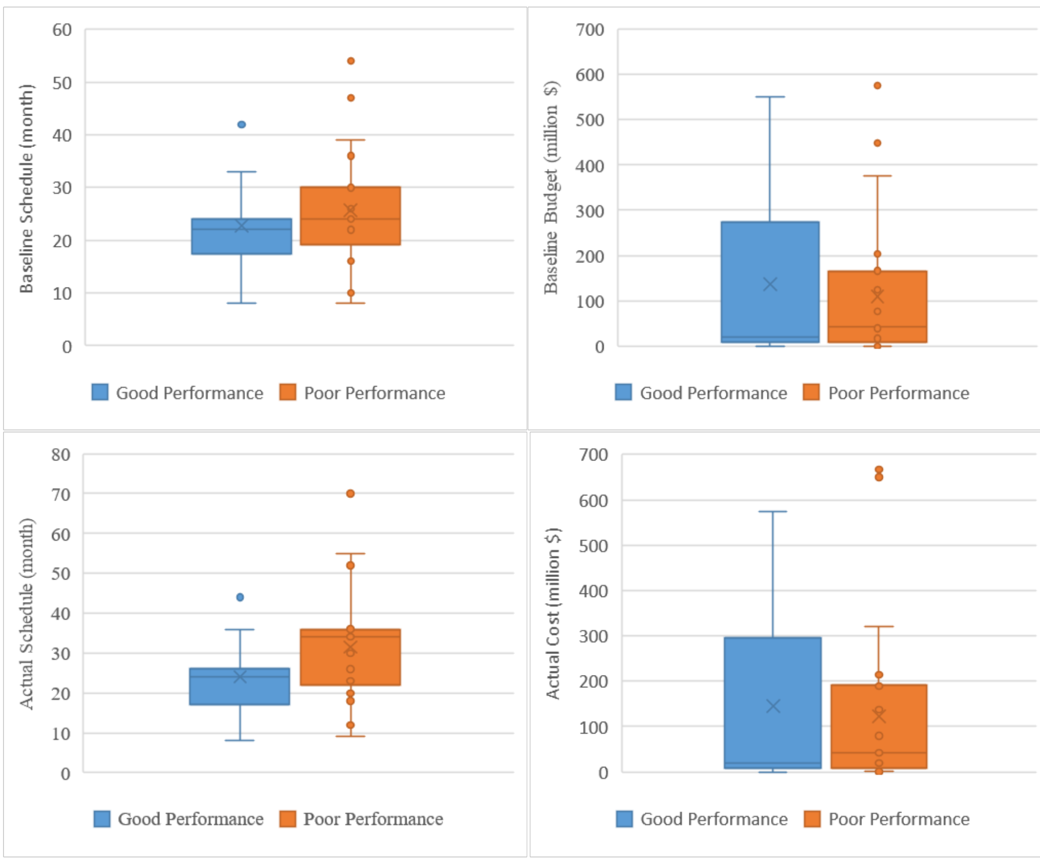

Figure 6-2. Box-plot of Poor and Good Performance Projects in Terms of Baseline and Actual Schedule/Cost

6.2. Statistical Data Analysis

The results were statistically analyzed to assess the relationship between different KPFs and construction performance in different EPC phases. As it is mentioned, all projects categorized into two groups on the basis of the magnitude of their performance. (1) Good performance projects having overrun/underrun less than 10% (2) Poor performance projects experiencing more than 10% deviation. In the meantime, various statistical analyses were applied to analyze the mean difference of KPFs between good performance projects and poor performance projects including two sample T-test and Kruskal-Wallis test. P-value is presented to indicate whether the results coming from the sample data, occurred by chance or not. The acceptance level for significant test is a p-value of 0.1, as Bobko (2001) explained this p-value can balance the possibility of identifying false relationship with the possibility of missing a significant correlation.

Two-sample T-test is usually utilized to compare whether the difference in average of two groups is significant or if it is instead due to random chance. It is applied to compare two groups with continuous data (numeric value) having normal distribution. Each hypothesis test needs the analyst to state a null hypothesis (H0) and an alternative hypothesis (H1). The hypotheses are stated in such a way that they are mutually exclusive meaning that they cannot both be true. The null hypothesis (H0) for this test is, the mean for good performance projects and poor performance projects is the same. While alternative hypothesis (H1) states that the means of both groups are different. Details related to the two-sample t-test were presented below (Armitage et al. 1994):

State Decision Role: If the T is greater than t-value (from table), then reject the null hypothesis.

Two Sample T-test:

$$T = \frac{\mu_1 - \mu_2}{\sqrt{\frac{S_1^2}{N_1} + \frac{S_2^2}{N_2}}}$$ *(*Formula 6-1)

Degree of freedom (d_f) = $$\frac{(\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2})^2}{\frac{1}{n_1 - 1}(\frac{S_1^2}{n_1})^2 + \frac{1}{n_2 - 1}(\frac{S_2^2}{n_2})^2}$$ *(*Formula 6-2)

Where:

μ_i= Sample i^{th} mean

S_i = Sample i^{th} Standard Deviation

N_i= Sample i^{th} Size

Kruskal-Wallis is rank-based nonparametric test which is employed for data not having normal distribution. In other word, in this test it is not assumed that variables originate from distribution that can be entirely described by two parameters; Mean and standard deviation. Hence, not only because of data type (Likert scale variable) but also due to the small number of results, it is rational to utilize nonparametric Kruskal-Wallis test. The null hypothesis of the Kruskal-Wallis test is, the probability that the median of good performance projects is greater than the median of poor performance projects is 0.5. On the other hand, this amount for the alternative hypothesis is considered to be less than 0.5. It should not be neglected that the two groups are assumed to follow an identically scaled distribution.

Details related to the two-sample Kruskal-Wallis were presented below (Theodorsson-Norheim, 1986):

State Decision Role: If the H is greater than χ^2 value (from table), then reject the null hypothesis.

Kruskal-Wallis Formula:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{K} \frac{R_i^2}{N_i} - 3(N+1) \qquad \text{(Formula 6-3)}$$

Degree of freedom = K-1

Where:

N = total number of observations

R = the rank for an individual sample

K = the number of groups

N_i = the number of observations in group i.

6.3. Result

The results of statistical analysis (p-values) between each key performance factors and construction cost and schedule performance in engineering phase were shown in Table 6-1. Each KPF has been coded with two letters, expressing the first letters of phase name (e.g. EP.1; Engineering Performance). The data analysis demonstrates that there is a significant relationship between “Change order driven by owner”, “Communication between design team”, “Slowness in decision making” and engineering schedule performance, having a P-value of less than 0.05. Sometimes, due to complicated and unforeseen situations in construction, owners or engineers prefer to take a short time in order to perform the best course of action. Although this delay in decision-making may result in cost saving or quality enhancement, it can affect the schedule performance of construction negatively. Besides, since construction is among one of the information dependent industries, lack of communication between different construction entities causes inefficient information exchange and therefore, trust and accountability decrease. Ineffective communication also creates an atmosphere bringing disagreement and conflicts, as construction participants cannot be aligned well. Subsequently, construction projects lead to have poor performance.

Further analysis revealed that “Difficulty in obtaining design approval” and “Low labor/staff productivity” are also significant within the 0.1 acceptance level in predicting engineering phase schedule performance. Most of the time multiple permits are required to start a project. Due to submission of an application and required documents for each permit, approval process is considered as time consuming one. In addition, loss of labor productivity forces responsible entity to do the same amount of work with equal resources in a longer time. On the other hand, a statistically significant relationship was found between “Consultant & Client experience”, “Lack of frequency of reporting” and engineering cost performance with P-values of 0.040 and 0.017 respectively. This relationship is also perceived between “Change order driven by owner”, “Financial stability of client” and engineering cost performance within the 0.1 acceptance level. It is interesting to note that three of these four significant KPFs were classified in “Client & Consultant” group indicating the decisive role of these two entities in cost performance of engineering phase. Moreover, a curious fact is that “Change order driven by owner” is the solely factor that can significantly affect both schedule and cost performance of engineering phase with p-value of “0.001” and “0.051” respectively. This relationship could be described as the immense importance of design changes on the performance of engineering phase, as it can cause additional work requiring enough efforts and resources to be done. Due to the nature of construction, changes in this industry is inevitable. Most of the time major changes require engineers to revise the drawings and send them for approval process again. Then, project management team should also devote more time to reschedule project and update client with the new estimation.

Therefore, any change order to construction can deviate construction performance from the baseline schedule and cost of the project.

Table 6-1. Engineering Phase Cost and Schedule Performance Factors

Group	**Engineering Performance Factors**		**P-Values**	
			Schedule Performance	Cost Performance
Change	EP.1	Change order during driven by owner	0.001**	0.051*
Management	EP.2	Communication between design team	0.004**	0.554
	EP.3	Slowness in decision making	0.023**	0.942
	EP.4	Late incorporation of emerging technologies	0.742	0.531
P.S.E	EP.5	Delay in approval stage	0.670	0.455
	EP.6	Difficulty in obtaining design approval	0.061*	0.744
	EP.7	Obtaining permits	0.333	0.763
Contract	EP.8	Type of Contract	0.227	0.560
Labor	EP.9	Low labor/staff productivity	0.076*	0.361
Client & Consultant	EP.10	Consultant & client experience	0.537	0.040**
	EP.11	Lack of frequency of reporting	0.523	0.017**
	EP.12	Poor scope definition	0.301	0.878
	EP.13	Financial stability of client	0.722	0.078*
Project-Characteristics	EP.14	Complexity of project	0.448	0.487

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

Table 6-2 specifies the relationship between KPFs and construction performance in procurement phase. According to this table, “Material Quality”, “Material shortage”, “Transportation delays”, “Imported labor” and “Slowness in decision making” were statistically proved that they could affect the schedule of procurement phase. Among these factors, “Material Quality” and “Imported labor” were significant with 95% confidence level. Particularly, if the quality of material is not up to the standards, then, it should be replaced or reordered which takes time and causes delay. Moreover, due to the labor shortage in some areas, construction industry is forced to employ imported labors, which may not be as productive as local labors. Even the hiring process of imported labor can take time or their adoption to the new environment could be a challenge. Therefore, utilizing imported labor may imposes many obstacles on the time and cost performance of projects.

Looking at the defined groups of KPFs indicates that material-related factors have the largest portion among the significant schedule performance factors in procurement phase with three significant factors. On the other hand, the cost performance of procurement phase is significantly affected by equipment-related factors comprising “Equipment shortage”, “Imported Equipment” and “Equipment Quality”. For instance, the price of equipment increases because of the bloom in economic condition of developing country and the number of qualified available equipment decreases. As a result, those rental-based contractors are obliged to utilize below-standard equipment and pay rent for more days to complete equipment-based activities (Ogunlana et al. 1996).

It may be worth mentioning that “Imported labor” and “Slowness in decision making” are the only common KPFs between two groups (schedule and cost), which can lead project to experience both delay and cost overrun. Due to higher order of qualified resources, demand may exceed supply and because of unavailability of resources, suppliers do not offer them for long time. Therefore, even little delay in decision making for providing resources may impose serious implications to the project goals and causes delay and cost overrun.

Table 6-2. Procurement Phase Cost and Schedule Performance Factors

Group	Procurement Performance Factors		P-Values	
			Schedule Performance	Cost Performance
Material	PP.1	Material Quality	0.021**	0.321
	PP.2	Material shortage	0.079*	0.804
	PP.3	Transportation delays	0.094*	0.711
	PP.4	Imported material	0.288	0.215
Labor	PP.5	Imported labor	0.039**	0.087*
	PP.6	Shortage of skilled and technical personnel	0.253	0.245
Management	PP.7	Construction site layout problem	0.855	0.619
	PP.8	Slowness in decision making	0.086*	0.049**
Contractor	PP.9	Contractor experience	0.734	0.549
Equipment	PP.10	Equipment shortage	0.645	0.048**
	PP.11	Imported Equipment	0.743	0.054*
	PP.12	Equipment Quality	0.846	0.084*

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

Table 6-3 illustrates the relationship between potential KPFs and construction performance in construction phase. As it is shown, since this phase includes most of construction processes, it has more number of KPFs affecting construction schedule/cost performance compared to that of other EPC phases. In the meanwhile, it is realized that 11 KPFs significantly influence time completion of construction phase. Having eight factors (out of 11) in “Management” and “Client & Consultant” groups indicates the significance of these two groups and their KPFs on the construction performance. One of the most imperative general schedule factors is lack of communication between different entities, which itself includes three significant factors in table 6-3; “Lack of communication between prime contractor organizations”, “Lack of communication between designer & contractor” and “Lack of communication between client & contractor”. It is also found that

“Management” group has the largest portion of the significant KPFs in the cost list of construction phase, with four indicators. This might spring to mind that substantial portion of time and cost overrun in construction phase can be addressed if construction practitioners apply effective managerial skills during construction phase. Table 6-3 reveals that there are eight significant KPFs deviating projects from both proposed schedule and cost in the execution stage. But solely three of them, are statistically significant with 95% confidence level in predicting both schedule and cost performance. These three KPFs are “Change order driven by owner”, “Slowness in decision making” and “Rework driven by contractor”. Mostly, rework is prompted by poor workmanship or accident on site, and change order results from owner’s change requirements. Each of these changes can be claimed as extra work which requires extra time and cost to be spent (Iyer et al. 2008).

Table 6-3. Construction Phase Cost and Schedule Performance Factors

Group		**Construction Performance Factors**	**P-Values**	
			Schedule Performance	Cost Performance
Change	CP.1	Change order driven by owner	0.002**	0.001**
Manageme nt	CP.2	Slowness in decision making	0.012**	0.034**
	CP.3	Lack of communication between prime contractor organizations	0.012**	0.651
	CP.4	Lack of communication between designer & contractor	0.053*	0.046*
	CP.5	Communication between sub-contractor	0.120	0.337
	CP.6	Lack of communication between design team &client	0.257	0.999
	CP.7	Lack of communication between client & contractor	0.069*	0.086*
	CP.8	Construction site layout problem	0.612	0.015**
	CP.9	Late incorporation of emerging technologies	0.646	0.680

Table 6-3 (Cont'd)

Contract	CP.10	Payment modality	0.260	0.030**
	CP.11	Risk sharing among the project team	0.688	0.764
Client & Consultant	CP.12	Rework driven by consultant	0.063*	0.016**
	CP.13	Inadequacy of site inspection	0.080*	0.097*
	CP.14	Consultant & client experience	0.088*	0.135
	CP.15	Financial stability of client	0.096*	0.900
	CP.16	Poor scope definition	0.190	0.776
P.S.E	CP.17	Obtaining permits	0.110	0.400
	CP.18	Delay in approval stage	0.580	0.658
Contractor	CP.19	Contractor's experience	0.088*	0.007**
	CP.20	Financial stability of contractor	0.983	0.536
	CP.21	Rework driven by contractor	0.042**	0.001**
Labor	CP.22	Shortage of skilled (Technical) personnel	0.139	0.092*
	CP.23	Low labor/staff productivity	0.594	0.700
Project-Characteristics	CP.24	Project location	0.188	0.493
	CP.25	Complexity of project	0.468	0.638
Material	CP.26	Material shortage	0.314	0.081*
	CP.27	Material quality	0.460	0.614
Equipment	CP.28	Equipment quality	0.588	0.200
External	CP.29	Economic condition	0.847	0.768
	CP.30	Domination of construction industry by foreign firms and aids	0.915	0.200

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

According to the table 6-3, contractor's experience was statistically found to have a significant impact in completing project on time with budgeted cost. The p-value for schedule and cost performance is 0.088 and 0.007 respectively. Owing to the complex nature of construction project, contractor might face a vast range of difficulties during the construction process. Inadequate contractor experience creates more difficulties taking longer period to be addressed or contractor might undertake risky actions for solving the problems.

6.4. Weight of Key Performance Factors

The result of all KPFs in different EPC phases were categorized into two different groups (good and poor performance groups) based on the performance of respondent's projects and were statistically tested to find if there is a significant difference between the means of two groups. Since the impact of each significant KPFs are different on the construction performance, a statistical effect size method was utilized to weight the impact size of each factor. It should be noted that there were two types of data employed in data analysis; numerical and ordinal values. Therefore, two different methods should be applied to calculate the effect size of each factor which prevents us to compare the weighting results of one factor from one category to the other one. Hence, we converted numerical values to the Likert-type scale with seven points to have a uniform database and utilize the same weighting method which allows us to later compare the calculated size effects of KPFs. Ultimately, the transformed data were weighted with Epsilon-Squared effect size method, as Tomczak & Tomczak (2014) expressed Epsilon-Squared is the most appropriate effect size test for Kruskal-Wallis and ordinal variables.

The effect sizes were computed utilizing the following equation:

$$E_R^2 = \frac{H}{(n^2-1)/(n+1)} \qquad (1)$$

H - Value obtained in the Kruskal-Wallis test

n - Total number of observations

E_R^2 - Coefficient assumes the value from 0 (indicating no relationship) to 1 (indicating a perfect relationship)

As it is mentioned above, E_R^2 expresses the magnitude of effect size ranging from 0 to 1. This magnitude basically depends on H, which is calculated in the Kruskal-Wallis test, and total number of observations. The summation of all inquired E_R^2 value was calculated and each E_R^2 value was divided by summation to get weight percentage shown in Table 6-4. Then, all the factors were ranked based on their weight percentage to find the most important factors affecting phase-based cost and schedule performance of construction projects.

Table 6-4 shows that “Communication between design team” occupies the first position with 33% effect size on engineering phase schedule performance. It is followed by “Slowness in decision making” and “Change order driven by owner” with 26% and 18% effect sizes respectively. Moreover, the cost performance of engineering phase is mostly affected by “Consultant & Client experience” and “Change order driven by owner”, the former with 44% and the later with 40% effect size in determining the cost performance behavior. It is obvious that “Change order driven by owner” is the most significant KPFs in engineering phase, as it is listed among top three most significant KPFs of both schedule and cost performance groups. This change order includes any additions or omissions to the scope of the work which can significantly impose major changes on the construction performance and lead project to encounter major time and cost overruns.

According to Table 6-4, “Slowness in decision making” has the highest impact on schedule performance of procurement phase and is ranked as the first among the list of key schedule performance factors, with 40% effect size. On the other side, “Equipment shortage” and “Imported equipment” are the primary causes of cost overrun in procurement phase with more than 30% effect size for each. However, the importance of

“Imported labor” should not be neglected, as it was ranked third in both schedule and cost list, with 17% and 29% effect size respectively.

Due to participating of many entities in construction phase, there are more factors which can have an effect on construction performance of this phase. In the meantime, lack of communication and information flow between these entities is one of the most important causes, which negatively impact performance of construction project and cause delay. As it is shown in Table 6-4, “lack of communication between prime contractor organizations” is ranked first in the schedule list, with 22% size effect. Moreover, “Lack of communication between designers and contractors” is also concluded that significantly affect construction schedule and cost performance. This factor, along with “Consultant & Client experience” and “Contractor experience” are rated as the second most influential factors postponing construction phase. Looking at list of cost performance factors in Table 6-4, it is indicated that “Contractor experience” and “Construction site layout problem” took the first and second positions respectively, with comparatively small difference. The first one occupies 18% and the later one has 16% effect size on the cost performance of construction phase. Interestingly, “Contractor experience” and “Lack of communication between designers and contractors” are the most important KPFs in construction phase, since they are common in the top three ranking of both lists of cost and schedule performance factors.

Table 6-4. Ranking of Phase-Based Cost and Schedule Performance Factors

Significant Performance Factors		Schedule			Cost		
		Weight	Weight Percentage	Rank	Weight	Weight Percentage	Rank
Code		Engineering Phase					
EP .1	Change order driven by owner	0.106	18%	Rank 3	0.129	40%	Rank 2
EP.2	Communication between design team	0.193	33%	Rank 1			
EP.3	Slowness in decision making	0.151	26%	Rank 2			
EP.6	Difficulty in obtaining design approval	0.078	13%	Rank 4			
EP.9	Low labor/staff productivity	0.061	10%	Rank 5			
EP.10	Consultant & client experience				0.141	44%	Rank 1
EP.11	Lack of frequency of reporting				0.032	10%	Rank 3
EP.13	Financial stability of client				0.019	6%	Rank 4
Procurement Phase							
PP.1	Material quality	0.123	20%	Rank 2			
PP.2	Material shortage	0.074	12%	Rank 4			
PP.3	Transportation delays	0.065	11%	Rank 5			
PP.5	Imported labor	0.100	17%	Rank 3	0.086	29%	Rank 3
PP.8	Slowness in decision making	0.244	40%	Rank 1	0.019	6%	Rank 4
PP.11	Equipment shortage				0.096	32%	Rank 1
PP.12	Imported equipment				0.094	31%	Rank 2
PP.13	Equipment quality				0.004	1%	Rank 5
Construction Phase							
CP.1	Change order driven by owner	0.067	9%	Rank 4	0.093	12%	Rank 4
CP.2	Slowness in decision making	0.003	0.4%	Rank 9	0.004	1%	Rank 10
CP.3	Lack of communication between prime contractors	0.159	22%	Rank 1			
CP.4	Lack of communication between designers and contractors	0.091	13%	Rank 2	0.102	13%	Rank 3
CP.7	Lack of communication between client and contractor	0.083	12%	Rank 3	0.075	10%	Rank 6
CP.8	Construction site layout problem				0.123	16%	Rank 2
CP.13	Payment modality				0.009	1%	Rank 10
CP.17	Rework driven by Consultant	0.022	3%	Rank 7	0.018	2%	Rank 9
CP.18	Inadequacy of site inspection	0.032	5%	Rank 6	0.033	4%	Rank 8
CP.19	Consultant & client experience	0.093	13%	Rank 2			
CP.20	Financial stability of client	0.014	2%	Rank 8			

Table 6-4. (Cont'd)

CP.25	Contractor experience	0.093	13%	Rank 2	0.137	18%	Rank 1
CP.27	Rework driven by contractor	0.053	7%	Rank 5	0.029	4%	Rank 8
CP.28	Shortage of skilled (Technical) personnel				0.052	7%	Rank 7
CP.32	Material shortage				0.081	11%	Rank 5

Table 6-5 illustrates the overlap between the identified KPFs within each of the three EPC phases. All significant KPFs and their relevant phases are illustrated in a tabulated format utilizing three different colors corresponding to the effect size of each KPF. According to Mangiafico (2016), if the value of Epsilon-Squared Effect Size is less than 0.1, the effect size is defined as small impact. Epsilon-Squared Effect Size between 0.1 and 0.2, indicates a medium impact and if it is greater than 0.2, the impact is the highest (large). The darker cells demonstrate the highest impact of factor, while the lightest one shows the lowest effect on construction performance. As it is seen in this table, "Slowness in decision making" was the only factor which has effect on schedule and cost performance of all EPC phases except cost performance of the engineering phase. This effect became more visible on the required time to complete the procurement phase. "Change order driven by owner" is another important factor in this table, as it is identified as the second factor affecting the cost and schedule performance of engineering and construction phases. Despite of low effect of this factor on the performance of construction phase, it has the medium effect on the performance of engineering phase. The remaining factors were significant in the cost and schedule performance list of only one or two phase(s), out of six possible combinations.

Table 6-5. The effect size of significant KPFs on the schedule and cost performance of EPC phases

Category	Performance Indicators	Engineering Phase		Procurement Phase		Construction Phase	
		Time	Cost	Time	Cost	Time	Cost
Contractor	Rework driven by contractor					S	S
	Contractor experience					S	M
Contract	Payment modality						S
Equipment	Equipment quality				S		
	Imported equipment				S		
	Equipment shortage				S		
Material	Transportation delays	S					
	Material shortage	S					S
	Material quality	M					
Client & Consultant	Inadequacy of site inspection					S	S
	Rework driven by consultant					S	S
	Financial stability of client		S			S	
	Lack of frequency of reporting		S				
	Consultant & client experience		M			S	
Labor	Shortage of skilled personnel						S
	Imported labor			M	S		
	Low labor productivity	S					
PSE*	Difficulty in obtaining design approval	S					
Change	Change order driven by owner	M	M			S	S
Management	Communication between design team	M					
	Slowness in decision making	M		L	S	S	S
	Lack of communication between contractors					M	
	Lack of communication between designer & contractor					S	M
	Lack of communication between client & contractor					S	S
	Construction site layout problem						M

S denotes Small Effect Size;
M denotes Medium Effect Size; and
L denotes Large Effect Size.

6.5. Weight Calculation of Cost and Schedule Performance Categories

Table 6-6 illustrates the total effect size of each category in different EPC phases in terms of cost and schedule performance. As it is shown in this table, the "management" category has the largest effect size in almost all six combinations, except in the cost performance of engineering and procurement phases. In the meantime, not only there is a zero effect size of management category on cost performance of engineering phase, but it also has extremely small effect size on cost performance of procurement phase. The existence of managerial factors in almost all phases reveals that construction management should be implemented from the scratch to the substantial completion of construction phase in order to save construction professionals enough money and time.

According to Table 6-6, "Client & Consultant" occupies dominant role in the cost performance of engineering phase, as it has 60% of total weight percentage. In addition, the important role of "Change" category in deviating time schedule and cost performance should not be neglected, as it can affect schedule and cost performance of both engineering and construction phases. "Change" category impacts cost performance of engineering phase with accumulated weight of 40%.

Regarding Procurement phase, as it is expected resources groups have the highest weight percentage. In the meanwhile, "Material" and "Equipment" categories have more impacts in comparison with that of other groups in the schedule and cost performance of procurement phase respectively. "Material" hold 43% of total weight percentage of schedule performance, followed by "Management" and "Labor" in the order mentioned in procurement performance. Furthermore, due to 64% effect of "Equipment" on cost performance of procurement phase, responsible entity should adopt policies to minimize equipment-related issues and saves money.

With respect to construction phase, it should be noted that “Management” places the first position in both schedule and cost performance of construction phases, with 47% and 40% of total percentage weight. It is followed by “Client & Consultant” and “Contractor” in the schedule list of construction phase respectively, with approximately one fifth of total percentage weight for each.

Table 6-6. Distribution of Significant KPFs According to Their Category

Phase		Category	Weight	Percentage Weight
Engineering Phase	Schedule Performance	Change	0.106	18%
		Management	0.344	59%
		PSE	0.078	13%
		Labor	0.061	10%
	Cost Performance	Change	0.129	40%
		Client & Consultant	0.192	60%
Procurement Phase	Schedule Performance	Material	0.262	43%
		Labor	0.100	17%
		Management	0.244	40%
	Cost Performance	Labor	0.086	29%
		Management	0.019	6%
		Equipment	0.194	64%
Construction Phase	Schedule Performance	Change	0.067	9%
		Management	0.336	47%
		Client & Consultant	0.161	23%
		Contractor	0.146	20%
	Cost Performance	Change	0.093	12%
		Management	0.304	40%
		Contract	0.009	1%
		Client & Consultant	0.051	6%
		Contractor	0.166	22%
		Labor	0.052	7%
		Material	0.081	11%

A comparison between the most frequent phase-based factors in the literature and significant factors that the author found from data analysis was made and demonstrated in table 6-7. Based on the red text which shows the common factors in the same phase, it is found that except schedule performance of engineering phase, there is no consistency between frequent factors' list and significant factors' list. Herein, "Communication between design team", "Slowness in decision-making" and "Change order driven by owner" were found to have significant effects on the time schedule of engineering phase and also they were frequently mentioned as key schedule performance factors in the literature of engineering phase. According to the Table 6-7, design change especially driven by in the cost list of engineering and construction phases and also material shortage in the schedule list of procurement phase are common in both columns. In other words, it seems there is one consistent factors between the finding of this paper and literature that can hammer schedule of procurement phase and cost performance of engineering and construction phases. It should be mentioned that the most frequent factors in cost performance of procurement phase and schedule performance of construction phase do not play a significant role in the performance of mentioned phases in industrial projects.

6.6. Best Practices

This study concentrates on the implementation of thirteen Best Practices (BPs), which help construction projects to have better performance in terms of cost and schedule. These thirteen BPs were taken from CII Benchmarking and Metrics, which are based at the University of Texas at Austin. Moreover, Construction Industry Institute (CII) is an association of more than 130 leading owners, engineers, contractors, and suppliers from both public and private areas.

Table 6-7. Comparison between the most frequent factors and the significant one

Phase		Frequent performance factors	Significant performance factors
Engineering Phase	Schedule	Design change	Communication between design team
		Slowness in making decisions	Slowness in decision-making
		Delay in approval stage	Change order driven by owner
		Poor communication between different stakeholders	
	Cost	Design change	Consultant & client experience
		Poor communication between different stakeholders	Change order driven by owner
		Project size	
Procurement Phase	Schedule	Shortage of Construction Material	Slowness in decision-making
		Equipment Shortage	Material quality
		Shortage of site labor	Imported labor
		Late Delivery of material and equipment	Material shortage
	Cost	Price fluctuations	Equipment shortage
		Poor economic conditions	Imported equipment
		Shortage of Construction Material	Imported labor
		Shortage of site labor	
Construction Phase	Schedule	Design change	Lack of communication between prime contractors
		Poor site management and supervision	Lack of communication between designer and contractor
		Severe weather condition	Consultant & client experience
		Financial issues by client	Contractor experience
	Cost	Design change	Contractor experience
		Severe weather Condition	Construction site layout problem
		Laws and regulations	Lack of communication between designer and contractor
		Inaccuracy and deficiencies in cost estimates	Change order driven by owner

These BPs are consisted of Constructability, Team Building, Alignment, Partnering, Front End Planning, Change Management, Material Management, Zero Accident Techniques (i.e., Safety), Planning for Start Up, Dispute Prevention and Resolution, Quality Management, Lessons Learned, and Project Risk Assessment. Table

6-8 demonstrates the definition of each best practice and their effects on the performance of project provided by Construction Industry Institute (CII).

Table 6-8. Definition of each best practices

Best Practices	Definition
Constructability	Constructability is the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels.
Team building	Team building is a project-focused process that builds and develops shared goals, interdependence, trust and commitment, and accountability among team members and it seeks to improve team members' problem-solving skills.
Alignment	Alignment is defined as "the condition where appropriate project participants are working within acceptable tolerances to develop and meet a uniformly defined and understood set of project priorities."
Partnering	Companies may partner in order to achieve specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is built on trust, dedication to common goals and the understanding of each other's individual expectations and values
Front end planning (FEP)	Front end planning (FEP) is the process of developing sufficient strategic information with which owners can address risk and decide to commit resources to maximize the chance for a successful project. FEP is a gated process that focuses on feasibility, concept and detailed scope phases of project development.
Change management	Change management is the process of incorporating a balanced change culture of recognition, planning, and evaluation of project changes in an organization to effectively manage project changes
Materials management	Materials management is an integrated process for planning and controlling all necessary efforts to make certain that the quality and quantity of materials and equipment are appropriately specified in a timely manner, are obtained at a reasonable cost, and are available when needed. The materials management system combines and integrates takeoff, vendor evaluation, purchasing, expediting, warehousing, distribution, and disposing of materials functions
Zero accident techniques	Zero accident techniques include the site-specific safety programs and implementation, auditing, and incentive efforts to create a project environment and a level of training that embraces the mindset that all accidents are preventable and that zero accidents is an obtainable goal.
Planning for start-up	Startup is defined as the transitional phase between plant construction completion and commercial operations, including all of the activities that bridge these two phases. Critical steps within the startup phase include systems turnover, check-out of systems, commissioning of systems, introduction of feed stocks, and performance testing

Table 6-8. (Cont'd)

Dispute Prevention and Resolution	Dispute resolution techniques include the use of a Disputes Review Board as an alternate dispute resolution process to eliminate the necessity to take disputes to litigation. The Dispute Review Board technique provides a process for addressing disputes in their early stages before the dispute affects the progress of the work, creates adversarial positions, and leads to litigation.
Quality management	Quality management incorporates all activities conducted to improve the efficiency, contract compliance and cost effectiveness of design, engineering, procurement, QA/QC, construction, and startup elements of construction projects.
lesson learned process	A lesson learned is knowledge gained from experience, successful or otherwise, for the purpose of improving future performance. Examples are: a lesson that is incorporated in a work process; a tip to enhance future performance; a solution to a problem or a corrective action; a lesson that is incorporated into a policy or a guideline; an adverse situation to avoid; and collective knowledge of "soon to retire" employees.
Project Risk Assessment	The process to identify, assess, and manage risk. The project team evaluates risk exposure for potential project impact to provide focus for mitigation strategies.

As it was mentioned previously, a question was designed for each BP on the basis of 7-point Likert-scale and provided in the survey. Herein, all BPs were statistically tested with the performance of each EPC phase to determine whether there is any significant difference between the mean of good and poor performance projects imposed by BPs. It should be noted that those BPs which were not applicable to a specific phase, were excluded from the analysis. Then, all significant phase-based KPFs found in the "Data Analysis" section of this research were statistically tested with these phase-based BPs, in order to find the most appropriate and significant BPs for each KPFs.

As a result of statistical data analysis, significant BPs improving the performance of each stage of construction process were found and presented in Table 6-9. "Material Management" and "Planning for Start-Up" were excluded from the engineering phase, as they are related to material and equipment used in the construction and procurement phases. “Zero Accident Techniques ” is also not applicable to engineering phase, since it is associated to site safety program and project environment.

Table 6-9. Level of Significance of each Best Practices with All EPC Phases

	Best Practices	P-Values					
		E.S.P	E.C.P	P.S.P	P.C.P	C.S.P	C.C.P
1	Constructability	0.001**	0.064*	0.536	0.598	0.060*	0.096*
2	Alignment	0.001**	0.089*	0.067*	0.934	0.092*	0.063*
3	Team Building	0.001**	0.647	0.773	0.762	0.082*	0.087*
4	Material Management	N/A	N/A	0.087*	0.080*	0.095*	0.081*
5	Project Risk Assessment	0.147	0.082*	0.873	0.202	0.063*	0.084*
6	Partnering	0.055*	0.068*	0.068*	0.078*	0.060*	0.083*
7	Quality Management	0.260	0.077*	0.067*	0.068*	0.077*	0.071*
8	Lessons Learned	0.093*	0.062*	0.083*	0.117	0.068*	0.090*
9	Front End Planning	0.048*	0.822	0.091*	0.077*	0.022**	0.118
10	Change Management	0.097*	0.065*	0.313	0.165	0.089*	0.029**
11	Dispute Prevention and Resolution	0.832	0.604	0.200	0.718	0.047**	0.094*
12	Planning for Start Up	N/A	N/A	0.149	0.324	0.427	0.497
13	Zero Accident Techniques (i.e., Safety)	N/A	N/A	N/A	N/A	0.027**	0.073*

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

As all BPs’ questions are designed based on Likert-scale, the results taken from the questionnaire are ordinal. Hence, Kruskal-Wallis was employed to statistically test the relationship between BPs (ordinal value) and construction performance (nominal value) of different EPC phases. In addition, the acceptable p-value is a value smaller than 0.1 significance level. According to Table 6-9, it is found that all BPs except “Planning for Start Up”, have a significant effect on the schedule performance of the construction phase. Apart from “Planning for Start Up”, cost performance of construction phase is not affected by “Front End Planning”, as the p-value is 0.118. A few of BPs were found to statistically impact engineering and procurement phases compared to the construction phase. Regarding engineering phase, there are 7 BPs which can improve schedule performance . Three of them are significant within 0.05 acceptance level including “Constructability”, “Alignment” and “Team building”, with the p-value of 0.001. Similarly, schedule performance of the construction phase has only three BPs (Front End Planning, Dispute Prevention and Resolution, Zero Accident Techniques) with a p-value less than 0.05.

Table 6-10 indicates the significant effect of each BP on the performance of different phases shown by shaded cells. As it can be seen, “Partnering” is the only best practice which can affect performance issues from the start of a project till its completion, as significant effect of “Partnering” can be observed in all 6 phases. It is widely accepted that building partnering approach among project teams not only creates effective communication and environment of mutual trust, but it also provides a harmonic context for project teams to work toward mutual goals and avoid possible claims and litigations. This technique is followed by “Alignment”, “Quality management” and “Lessons learned” enhancing the performance of 5 phases (out of 6). Regarding “Lessons learned”, it does not matter if experience is positive resulting from successful approach or negative arising from failure. The most important concern is that lessons learned by experience should eliminate potential failure from future works and develop positive results. Furthermore, lack of alignment with project objectives between project teams can pose many obstacles to the success of a project. The existence of a good alignment is critical, particularly from the beginning of a project when the project is being shaped. “Quality Management” is the act of monitoring all activities needing a specific level of greatness. “Quality Management” focuses not only on quality improvement of EPC phases, but also on the means to achieve it.

“Change Management”, “Front End Planning”, “Material Management” and “Constructability” occupied the third position on the list, as they are found to have significant impact on the performance of 4 phases. Since change in construction projects is inevitable, it is of importance for project management teams to control and handle new circumstances after change is applied. Change management includes methods that refine the utilization of resources, allocate the proper budget, plan changes in the best possible way, etc. Material management regarding planning and controlling of the flow of material and equipment should be available when needed. This method should be employed from the planning stage, continue through sourcing, purchasing, shipping, and storing stages, and end with controlling materials and providing service to construction projects.

Table 6-10. The Effect of each Best Practice on Different the EPC Phases

	Best Practices	Engineering		Procurement		Construction	
		Schedule	Cost	Schedule	Cost	Schedule	Cost
1	Constructability	■	■			■	■
2	Alignment	■	■	■		■	■
3	Team Building	■				■	■
4	Material Management	N/A	N/A	■	■	■	■
5	Project Risk Assessment		■			■	■
6	Partnering	■	■	■	■	■	■
7	Quality Management		■	■	■	■	■
8	Lessons Learned	■	■	■		■	■
9	Front End Planning	■		■	■	■	
10	Change Management	■	■			■	■
11	Dispute Prevention and Resolution					■	■
12	Planning for Start Up	N/A	N/A				
13	Zero Accident Techniques (i.e., Safety)	N/A	N/A	N/A	N/A	■	■

In the meanwhile, “Change Management” and “Constructability” have capability of reducing the potential cost overrun and delay in both engineering and construction phases. However, it should be noted that both schedule and cost performance of procurement phase can be boosted by “Material Management”, “Partnering”, “Quality

Management" and "Front end planning". Interestingly, "Dispute Prevention and Resolution" and "Zero Accident Technique" are identified as the only BPs affecting the performance of one phase (construction phase).

Although applying all BPs to a project is beneficial for the final performance of the project, due to many reasons construction practitioners might not be able to take advantages of all BPs. That is where the importance of understanding the most appropriate BPs for each significant KPF emerges. Therefore, it is imperative for the construction entities to find the significant KPFs which are related to the scope of their work and then, put all their resources and energies on identifying the acceptable BPs for those driven KPFs. In the meantime, the top three KPFs having more weight in each phase were selected to be statistically tested with the significant phase-based BPs. The results of tests and the relationship between each factor and its relevant BPs were depicted in Table 6-11. As it is shown, all 6 phases have three top weighted KPFs, except the schedule performance of the construction phase. Due to existence of three factors with rank 2 (Table 6-4), schedule list of construction phase has 5 factors in Table 6-11. According to the Table, "Alignment" is the most important BP in the construction phase especially in schedule performance list, as it can address the issues resulting from 5 top ranked factors (out of 8) in the whole construction phase. "Front End Planning" plays the same role for procurement phase, since it affects two top weighted factors in each of schedule and cost lists.

Regarding schedule performance of engineering phase, it is found that there is a statistically significant correlation between "Team Building" and "Lack of Communication Between Design Team", with P-value of 0.004. In other words, applying "Team Building" technique results in an increase in the social relationship between team members and forces them to involve themselves into collaborative tasks. Consequently, the communication between design teams is enhanced and the schedule performance of engineering phase is improved.

There are five BPs which can compensate lack of experience of consultants and clients during the engineering phase and improve the cost performance. These BPs are “Constructability”, “Risk Assessment Process”, “Alignment”, “Quality Management” and “Lesson Learned”, which the last three BPs are statistically significant within 0.05 significance level. As it is seen in the schedule list of the procurement phase, “Partnering” can address the issues attributed to “Slowness in Decision Making”, as it is statistically significant, with p-value of 0.058. In fact, “Partnering” provides a context for all entities to effectively communicate and it also increases information flow among them. Furthermore, “Partnering” can create shared-goals and objectives among different stakeholders and sets a trusting relationship between them. Therefore, in case of any problem, all entities can share their perceptions together very easily and this will accelerate the decision-making process. Also, implementing “Front End Planning” techniques was found to tackle resource-related deficiencies revealed in procurement phase. Applying “Front End Planning” helps to select a proper contracting strategy reducing the potential risks and uncertainties. It also helps projects to be procured on time with cost beneficial and qualified resources.

According to the cost performance of construction phase, it is found that there is a significant correlation between “Lessons Learned Process”, “Constructability” and “Contractor Experience”. Evidently, each project, even the most successful project, has lessons to learn. Hence, it is necessary for contractors to document and analyze all projects that they have done before. As a result, they can use their findings in the future works and enhance their experience. Moreover, it is concluded that “Zero Accident Technique” can solve problems resulting from improper construction site layout. These issues include inappropriate storage causing damage in material, poor sitting of plants, improper site access, and security and safety issues. Applying “Zero Accident Technique” not only provides a safety program to create a secure and dynamic environment, but it also offers a level of training to set the belief that all accidents are preventable. According to the table 6-11, it is deduced that lack of communication between prime contractors and also between designers and contractors can be confronted by setting a good alignment among involved entities. In addition, effective internal communications between prime contractors have not been established, however, by means of implementing the team building technique, there can be an increase in social relationships, enhancement of trust among prime contractors and avoidance of disputes.

Table 6-11. The Relationship of Top-Ranked KPFs with BPs

Phase		Factor	Constructability	Team Building	Alignment	Partnering	Front End Planning	Risk Assessment Process	Materials Management	Quality Management	Lessons Learned Process	Change Management	Zero Accident Techniques	Dispute Review
Engineering Phase	Schedule	Lack of communication between design team	0.759	**0.004****	0.198	0.399	0.514	N/A	N/A	N/A	0.081	0.436	N/A	N/A
		Slowness in decision making	0.129	0.621	0.247	**0.058***	0.178	N/A	N/A	N/A	0.124	0.428	N/A	N/A
		Change Order Driven by Owner	0.761	0.744	0.351	0.392	0.304	N/A	N/A	N/A	**0.082***	**0.076***	N/A	N/A
	Cost	Consultant & Client experience	**0.079***	N/A	**0.011****	0.745	N/A	**0.089***	N/A	**0.045****	**0.022****	1.000	N/A	N/A
		Change Order Driven by Owner	0.761	N/A	0.351	0.392	N/A	0.53	N/A	0.200	**0.082***	**0.076***	N/A	N/A
		Lack of Frequency of reporting	0.344	N/A	0.064	0.319	N/A	**0.079***	N/A	0.135	0.627	0.102	N/A	N/A
Procurement Phase	Schedule	Slowness in decision making	N/A	N/A	0.247	**0.058***	0.178	N/A	0.294	0.642	0.124	N/A	N/A	N/A
		Material Quality	N/A	N/A	0.108	0.350	**0.095***	N/A	0.142	0.156	0.144	N/A	N/A	N/A
		Imported labor	N/A	N/A	0.398	0.743	**0.052***	N/A	0.179	0.723	0.174	N/A	N/A	N/A
	Cost	Equipment Shortage	N/A	N/A	N/A	0.839	**0.080***	N/A	0.903	0.732	N/A	N/A	N/A	N/A
		Imported Equipment	N/A	N/A	N/A	0.548	0.968	N/A	**0.084***	0.873	N/A	N/A	N/A	N/A
		Imported labor	N/A	N/A	N/A	0.743	**0.052***	N/A	0.179	0.723	N/A	N/A	N/A	N/A

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

Table 6-11. (Cont'd)

Construction Phase	Schedule	Lack of communication between prime contractors	0.651	**0.091***	**0.072***	0.105	0.318	0.529	0.113	0.717	0.291	0.515	0.876	0.108
		Lack of communication between designers and contractors	0.895	0.617	**0.074***	**0.086***	0.810	0.827	0.809	0.527	0.415	0.339	0.307	0.551
		Contractor experience	**0.071***	0.979	0.925	0.611	0.114	0.354	0.644	0.785	**0.071***	0.783	0.345	0.859
		Consultant & Client experience	**0.079***	0.185	**0.011****	0.745	0.197	**0.089***	**0.078***	**0.045****	**0.022****	1.000	0.116	0.497
		Lack of communication between client and contractor	0.930	0.427	**0.063***	**0.091***	0.143	0.138	0.118	0.234	0.110	0.105	0.438	0.959
	Cost	Contractor experience	**0.071***	0.979	0.925	0.611	N/A	0.354	0.644	0.785	**0.071***	0.783	0.345	0.859
		Construction site layout	0.691	0.467	0.288	0.193	N/A	0.102	0.118	0.132	0.134	0.180	**0.067***	0.202
		Lack of communication between designers and contractors	0.895	0.617	**0.074***	**0.086***	N/A	0.827	0.809	0.527	0.415	0.339	0.307	0.551

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

6.7. Summery

All the results of respondents were collected and descriptively and statistically analyzed in this chapter. Generally, 44 responses were received and analyzed. In the first section of this chapter, a detailed information about the background of respondents, overall and phase-based cost and schedule of studied projects were presented. Then different statistical tests (Kruskal-Wallis and two sample T-test) were employed to identify the significant schedule and cost performance factors in different EPC phases. In the next step, by means of Epsilon Squared Effect Size method, the correlation between different best practices and significant factors was tested in order to find best course of actions for each performance factors.

Chapter 7

Conclusion and Future Research Recommendations

Nowadays, construction industry suffers from poor performance, mostly in terms of time and cost. The objectives of this research was primarily to identify the phase-based Key Performance Factors (KPFs) which lead to construction time and cost deviations, and then, to calculate their weights to prioritize these factors. To serve this purpose, a comprehensive list of potential phase-based cost and schedule performance factors were identified from the literature and classified into twelve categories. Based on the potential performance factors, a detailed questionnaire was developed to collect the general characteristics and performance information of construction projects. Then, two statistical testes (Two Sample T-Test and Kruskal-Wallis) were applied to explore whether there is a significant relationship between KPFs and construction schedule/cost performance in each EPC phase. To prioritize significant KPFs, Epsilon-Squared Effect Size method was utilized, and all significant factors were ranked to identify the most important ones affecting schedule and cost performance of construction projects.

This research also aimed to find the most appropriate Best Practices (BPs) for significant identified KPFs in order to prevent potential delay and cost overrun in construction projects. Herein, a list of 13 imperative BPs was found from CII Benchmarking and Metrics and statistically tested with the performance of each EPC phase. Then, the top ranked phase-based KPFs were analyzed with significant BPs in the relevant phase to see which BP(s) is/are the most appropriate one(s) to address the issues resulting from the mentioned KPFs.

As a result, it was proven that “Change Order Driven by Owner” is the most important key factor leading engineering phase performance to encounter delay and cost overrun. It is found the schedule performance of engineering phase is considerably impacted by “Lack of Communication Between Design Team” and “Slowness in Decision-Making”. On the other hand, “Consultant & Client Experience” was concluded to have a major effect specifically on the cost performance of engineering phase. With respect to construction phase, we found that “Contractor Experience” is the most weighted KPF influencing both schedule and cost performance of this phase. However, construction schedule performance itself was highly affected by “Lack of Communication Between Prime Contractor Organizations”. Regarding procurement phase, although material-related and managerial KPFs have the highest impact on overrunning the time, it was found that cost performance of this phase is extremely impacted by the equipment-related KPFs. In the meantime, “Equipment Shortage” and “Imported Equipment” were found as the most determinant KPFs leading the procurement phase to deviate from the budgeted cost. Looking at the schedule performance of the procurement phase, “Slowness in Decision-Making” seems to have the highest effect among all the significant factors.

In addition to identification of BPs for top-ranked phase-based KPFs, it is concluded that “Partnering” is the most important BP which can possibly affect both time schedule and cost performance of each single EPC phase of construction projects. It is followed by “Alignment”, “Quality Management” and “Lessons Learned”.

The finding of this study creates a comprehensive framework for academic researchers to carry out further studies. Also, PMs and construction practitioners can allocate more resources to the most critical factors, activities and phases, and they are also able to implement the appropriate BPs. As a consequence, significant amount of money and time will be saved and projects will be completed in a timely manner within the initial proposed cost.

It is recommended to the future scholars to conduct further research regarding phase-based performance factors and their best practices in industries other than industrial projects such as building, infrastructure and underground projects. Furthermore, academic researchers can examine the effect size of different significant BPs on the specific factors and prioritize them.

7.1. Limitations

During this study, the author encountered several limitations. First of all, the number of respondents from questionnaire was limited to 44, which is small in number but enough to draw a conclusion. Furthermore, since some respondents did not answer a few questions in the survey, there was some missing data in the results of the survey.

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Appendix A

List of Performance Factors Caused Cost and Time Overrun

Table 9-1. List of Performance Factors Caused Cost and Time Overrun

No.	Construction Performance Indicator
1	Change orders/variations of work
2	Poor management by contractor
3	Unforeseen condition
4	Financial problems by client
5	Delay in performing inspection and testing
6	Delay in decision making involving all project team
7	Deficiencies in planning and scheduling
8	Geological Conditions/ Terrain Condition
9	Construction mistakes and defective work
10	Contractors' financial difficulties
11	Lack of communication and coordination between the parties involved in construction
12	Mistakes in design
13	Payment delay
14	Poor weather condition
15	Delay in approval process
16	Planned time for project construction/Unrealistic contract durations imposed by client
17	Low labor productivity
18	Disputes/conflicts
19	Obtaining permit/approval from the municipality/different government authorities
20	Failure/breakdown of equipment
21	Inadequate contractor experience
22	Construction method
23	Client characteristics
24	Subcontractors issues (skill, quality, …)
25	Political situation/Government requirements
26	Lack of identification of needs/Unclear initial design brief
27	Poor contract management
28	Quality of material
29	Poor organization of the contractor
30	Poor design
31	Poor skills and experience of labor
32	Lack of consultant’s team experience

Table 9-1. (Cont'd)

33	Incomplete documents (Drawing, specification, …)
34	Excessive bureaucracy
35	Unavailability of Incentives given to the contractor
36	Delays in subcontractors' work
37	Delay in design information (work)
38	Materials changes in types and specifications during construction
39	Social and cultural factors
40	Quality assurance and control
41	Deficiencies in clients' organizational set-up
42	The relationship between different subcontractors' schedules
43	Rework by consultant and contractor
44	Lack of database in estimating activity duration and resources
45	Emergency works
46	Negotiations and obtaining of contracts
47	Material procurement
48	Nationality of laborers
49	Unskilled operator
50	Poor project management assistance/Supervision too late
51	Poor organization of the consultant
52	Mistakes in soil investigation
53	Controlling of subcontractor by general contractor
54	Preparation of scheduling networks and revisions by consultant while construction is in progress
55	Type of contract
56	Mistakes and discrepancies in contract documents
57	Disagreement on contract clauses and specification
58	Low bid/Contractors' unrealistic tenders
59	Damage of materials in storage
60	Risk sharing among the project team
61	Absence of consultant's site staff
62	Inflexibility of consultant
63	Poor procurement programming of materials
64	Lack of site contractor's staff
65	Staffing problems
66	Difficulties in obtaining energy (electricity, fuel)

Table 9-1. (Cont'd)

67	Difficulties in obtaining construction licenses
68	Desire to use alternative material/new technology
69	Delay to furnish and deliver the site to the contractor by the owner
70	Suspension of work by owner
71	Number of sub-contractors involved
72	Design cost
73	Complexity of design and construction
74	Insufficient data collection and survey before design
75	Monthly payment difficulties
76	Deficiency in cost estimates prepare
77	Insufficient background of proposed site
78	lack of experience of project type
79	Late inclusion of third parties
80	Shortage of materials on site
81	Equipment allocation problems
82	Inappropriate overall organizational structure linking all project teams
83	Ignoring critical tasks
84	Delayed or long process times by other authorities
85	Non-utilization of professional construction/contractual management
86	Failure to coordinate the final inspection or certification
87	Failure to coordinate and plan the owner's Move-in Sequence
88	Equipment Shortage (Machine and its parts)
89	Shortage of site labor
90	Late Delivery of material and equipment
91	Price fluctuations (material…)
92	Material Imported
93	Shortage of skilled (Technical) personnel
94	Equipment productivity (Quality, Age, production…)
95	Poor economic conditions (currency, inflation rate, Interest rate, etc.)
96	Difficulties in transportation (e.g. material…)
97	Market conditions (availability of resources)
98	Labor Supply
99	Nominated suppliers
100	Unavailability of utilities in site

Table 9-1. (Cont'd)

101	Delay in providing services from utilities (such as water, electricity)
102	Storage problems on site
103	Slow maintenance
104	Imported Plant
105	High cost of labor
106	High cost of machineries
107	Late incorporation of emerging technologies (software…)
108	Improper selection of subsequent consultants
109	Unclear authority among designers
110	Insufficient training of designers
111	Mistakes/changes in the generated shop drawings by contractor
112	Delay in responding to employer's queries by contractor
113	Unrealistic client's initial requirements
114	Project Priority
115	Project Characteristics (Type, Size, Complexity…)
116	Slow land expropriation due to resistance from occupants
117	Feasibility of project
118	Poor scope definition
119	Phase Involvement (Contract Type)
120	Inadequate integration on project interfaces
121	Lack of coordination among members of the design team

Appendix B

List of Acronyms

AEC	Architecture, Engineering and Construction
BPs	Best Practices
CCP	Construction Cost Performance
CII	Construction Industry Institute
C.P.I.	Cost Performance Index
CSP	Construction Schedule Performance
ECP	Engineering Cost Performance
EPC	Engineering, Procurement and Construction
ESP	Engineering Schedule Performance
F.I.	Frequency Index
GDP	Gross Domestic Product
I.I	Importance Index
KPFs	Key Performance Factors
LLP	Lessons Learned Programs
M.S	Mean Score
P.S.E.	Planning, Scheduling and Estimating
PCP	Procurement Cost Performance
PSP	Procurement Schedule Performance
PM	Project Management
R.I.I.	Relative Important Index
S.I.	Severity Index
UAE	United Arab Emirates
WA	Weighted Average

Appendix C

Distribution of respondents' answers

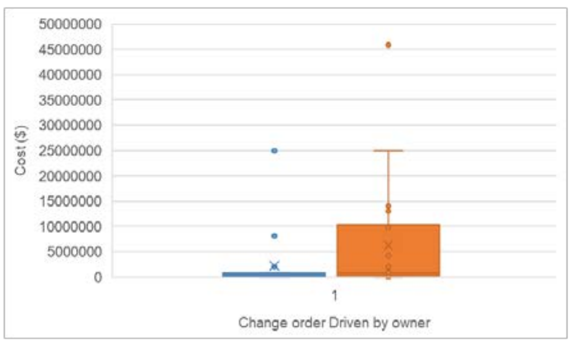
to each question in the survey

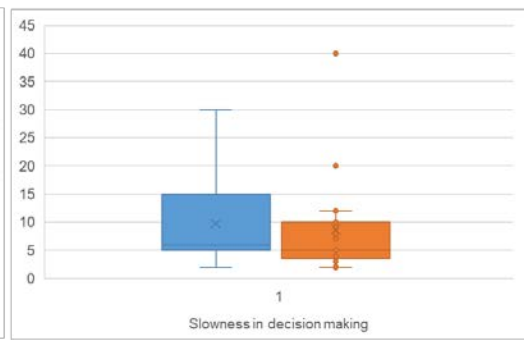
In this appendix, respondents' answers were distributed into two groups (good and poor performance projects) and the distribution of their responses were shown in the box plots. Basically, the X-axis expresses the name of factors or best practices and the Y-axis indicates the unit or the level of respondent's agreement with respect to the factor.

Key Performance Factors

Change Order Driven by Owner: How much was the change order added to project which was driven by owner?

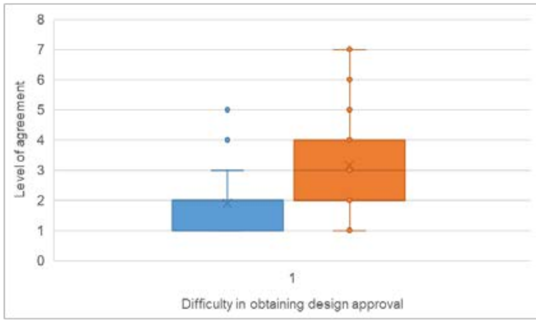
Slowness in Decision Making: How many stakeholders had an active role in decision making on the project?

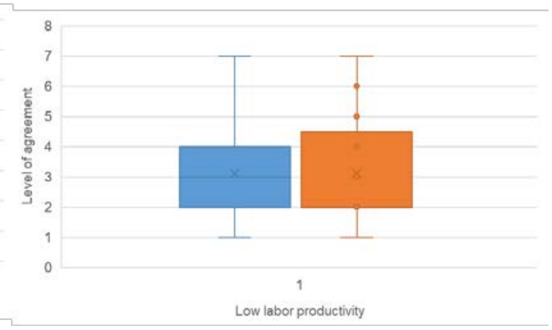




Difficulty in Obtaining Design Approval: What was the difficulty in obtaining design approvals?

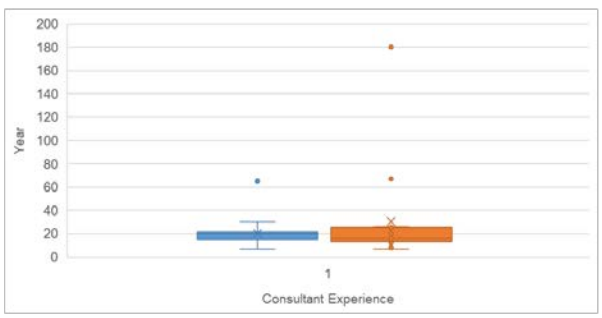
Labor Productivity: Please rate quality issues with field craft labor during project construction.

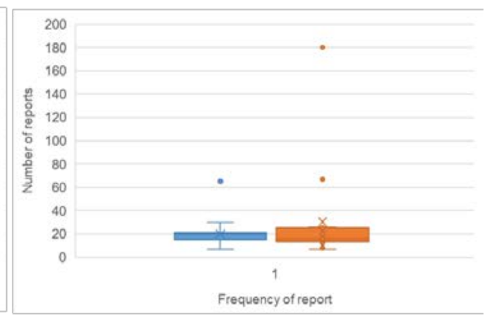




Consultant Experience: Please indicate the total experience of consultant team members?

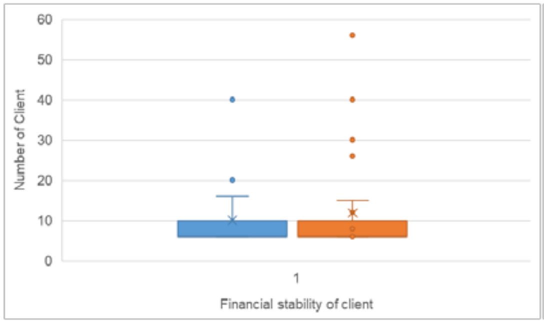
Frequency of Reports: Approximately how many regular status reports were completed in six months by the project team that are intended for executive management?

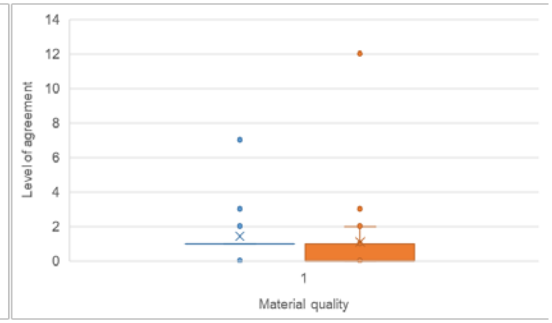




Financial Stability of client: How many total sponsoring entities existed on this project?

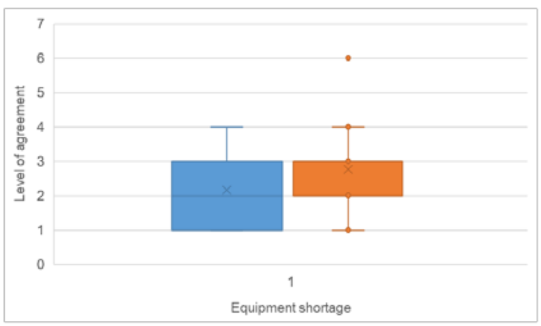
Material Quality: Please rate quality issues with bulk materials during project execution.

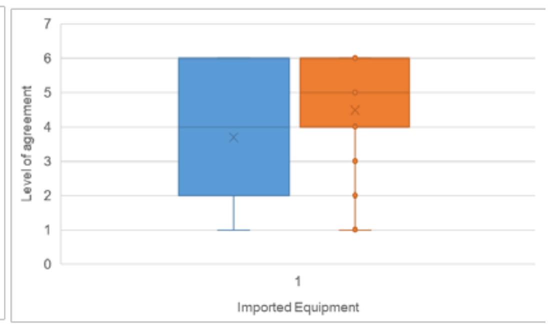




Equipment Shortage: What percentage of the time were equipment available for the project compared to the initial planning?

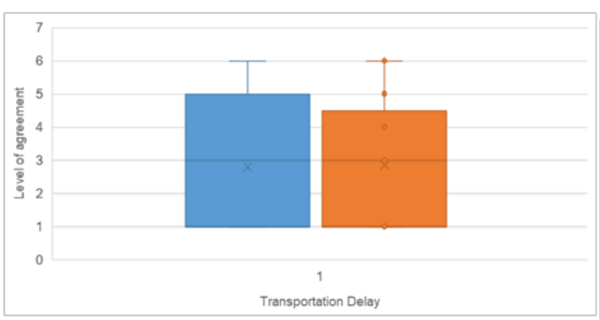
Imported Equipment: What percentage of Permanent (Tagged) Equipment was sourced within the project country?

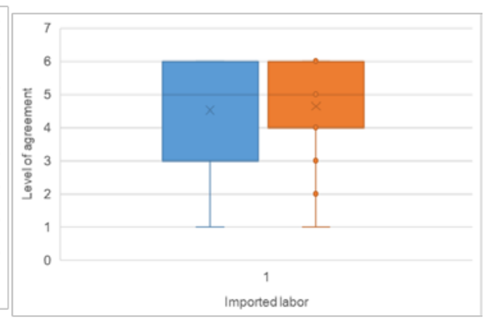




Transportation Delay: Was the delivery of permanent facility equipment delayed?

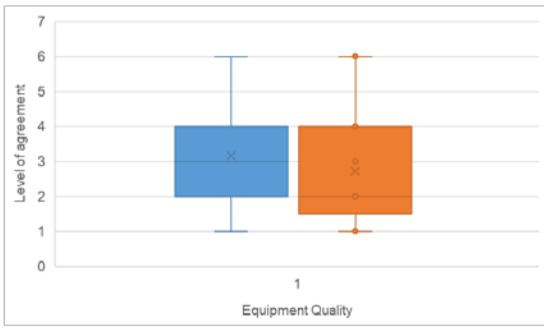
Imported Labor: What percentage of craft labor was sourced locally?

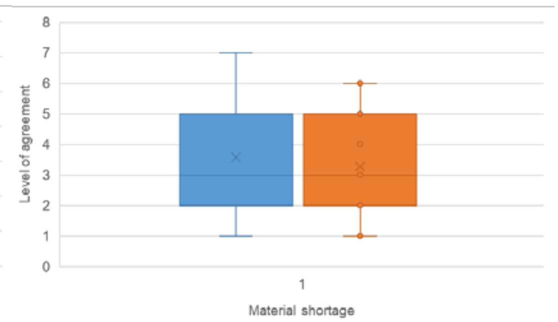




Equipment Quality: Please rate quality issues with the permanent (tagged) equipment during project execution.

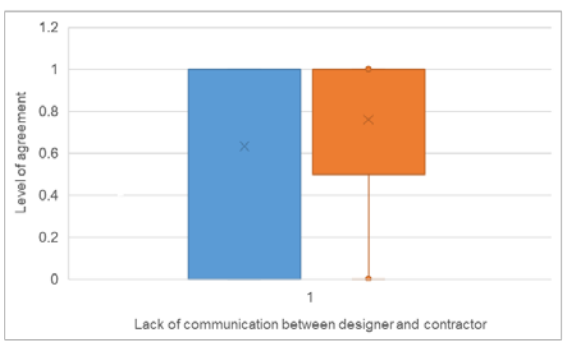
Material Shortage: To what extend materials were available when needed to support construction?

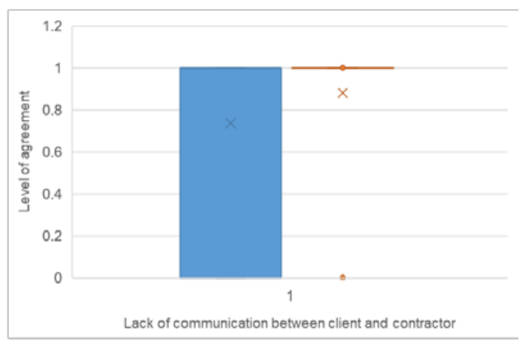




Lack of Communication between Designer and Contractor: How effective was the communication between designer and contractor?

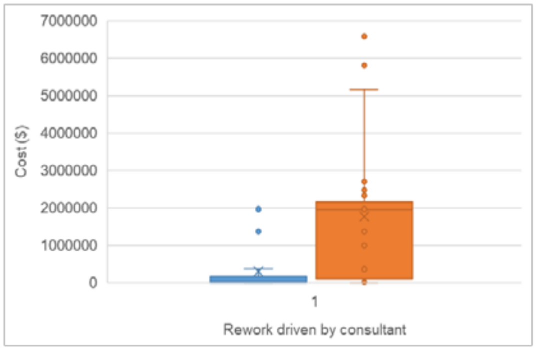
Lack of Communication between Prime Contractor Organization: How effective was the communication between prime contractor organizations?

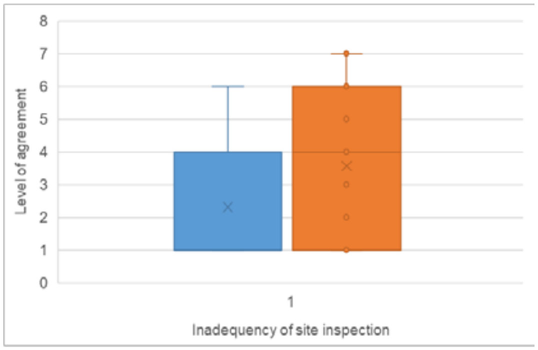




Inadequacy of Site Inspection: What was the impact of required inspection by external (regulatory) agencies/entities on original project execution plan?

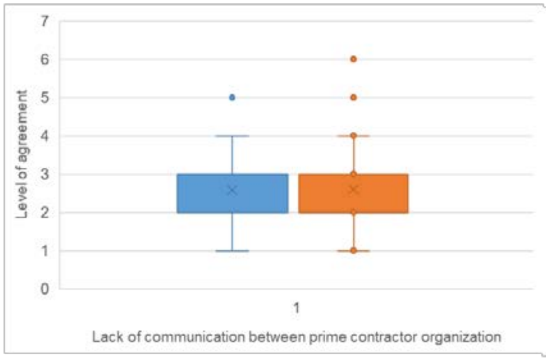
Rework Driven by Consultant: How much was the rework added to project which was driven by consultant?

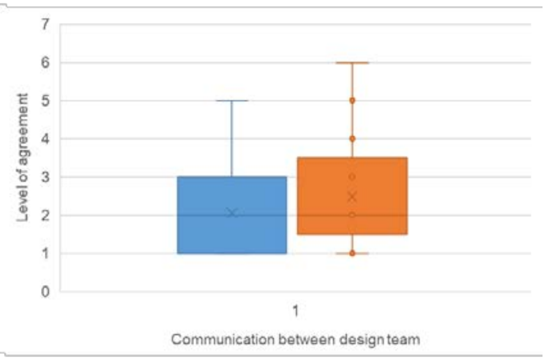




Lack of communication between prime contractor organization: How effective was the communication between prime contractor organizations?

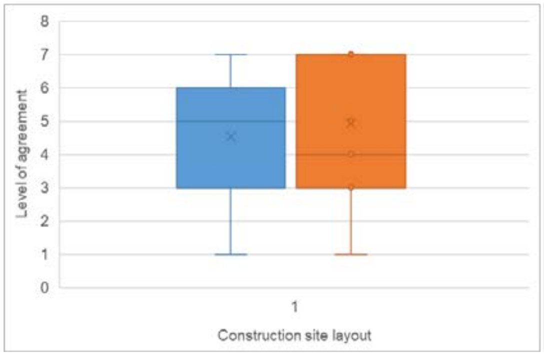
Lack of communication between design teams: How effective was the communication between design teams?

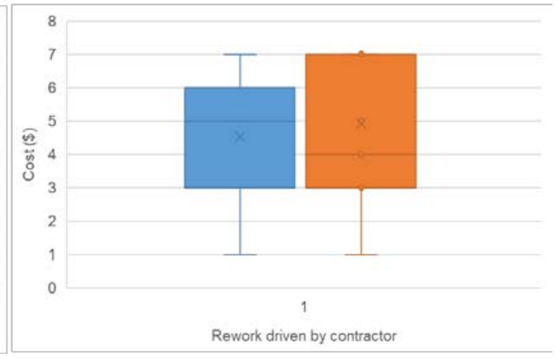




Rework Driven by Contractor: How much was the rework added to project which was driven by consultant?

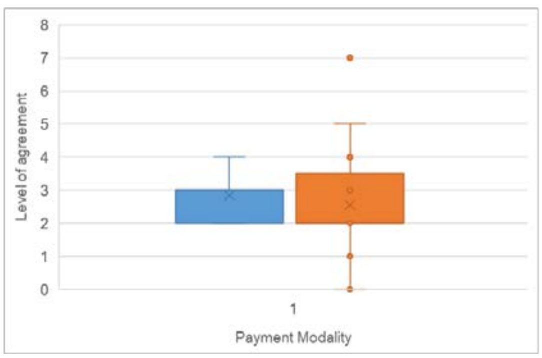
Construction Site Layout: To what extent, the construction site layout was affected on the performance of the selected project?

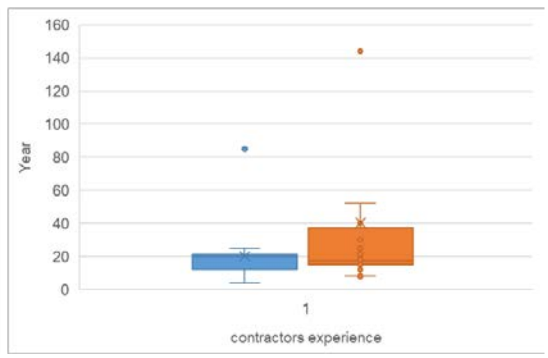




Payment Modality: Was the funding process well understood during the Front End Planning phase?

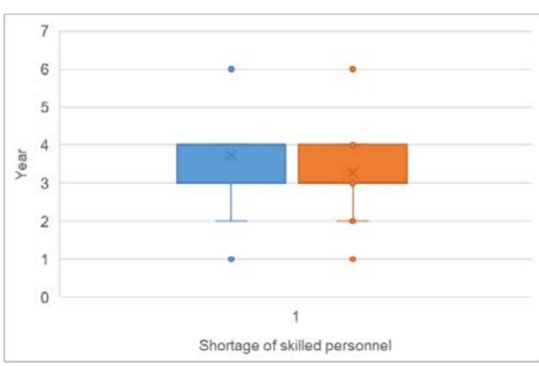
Contractor Experience: Please indicate the total experience of contractors?

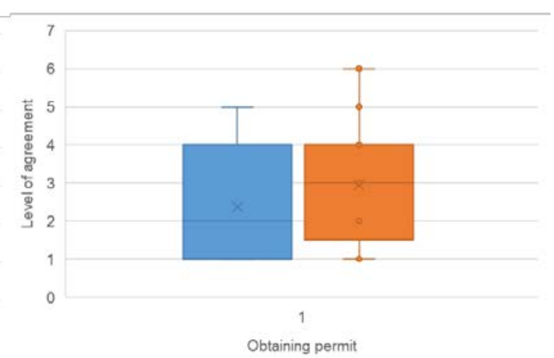




Shortage of Skilled Personnel: What percentage of skilled personnel actually worked on the project compared to planned resources?

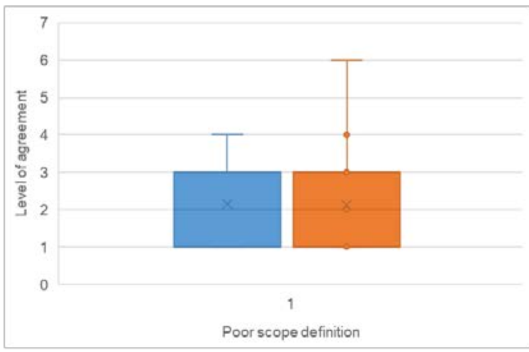
Obtaining Permit: What was the difficulty in obtaining permits?

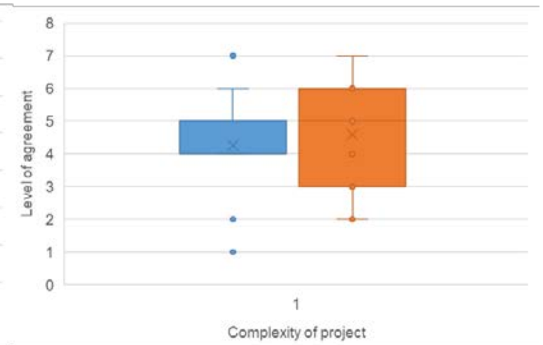




Poor Scope Definition: Was the process for defining the project's scope understood during the selection of designers and contractors?

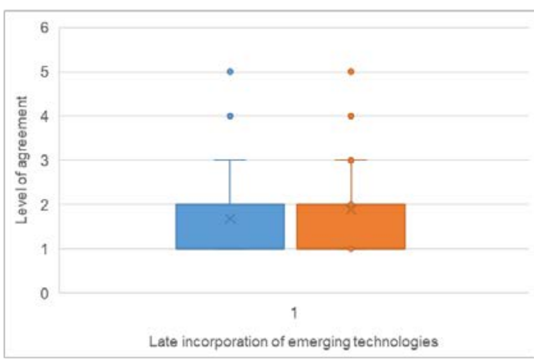
Complexity of Project: Please rate the overall complexity of this project on the 7 points Liker-Scale

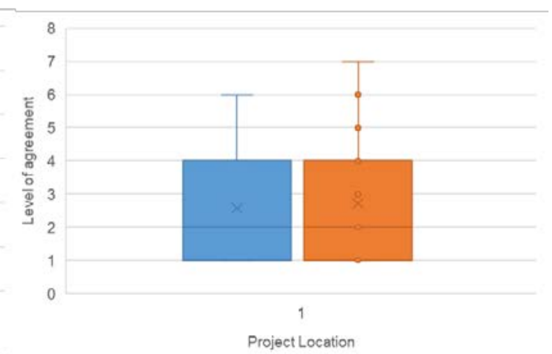




Late Incorporation of Emerging Technologies: What was your company's degree of familiarity with technologies that were involved in each EPC phases?

Project Location: What impact did the project location have on the project execution plan?

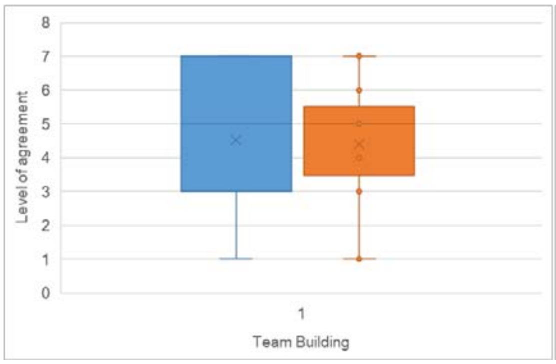


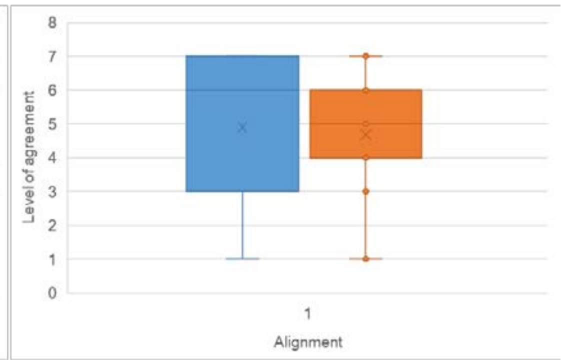


Best Practices

Team Building: Based on the definition, to what extent was Team Building implemented on this project?

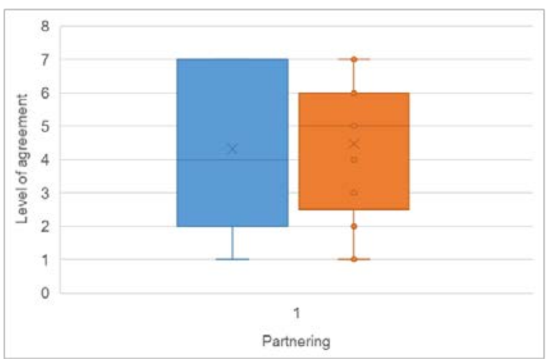
Alignment: Based on the definition, to what extent was an Alignment process implemented on this project?

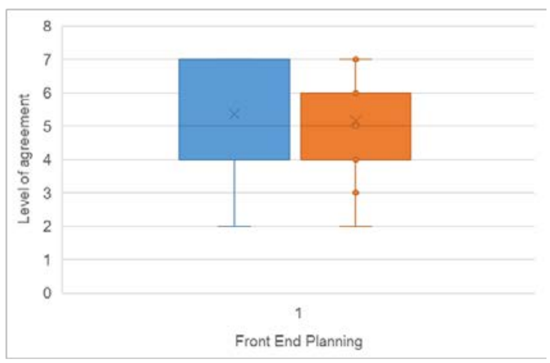




Partnering: Based on the definition, to what extent was Partnering implemented on this project?

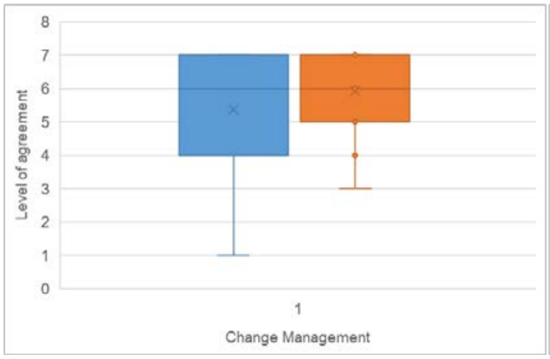
Front End Planning: Based on the definition, to what extent was a Front End Planning process implemented on this project?

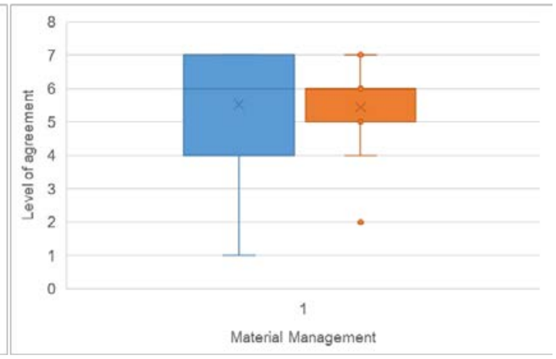




Change Management: Based on the definition, to what extent was Change Management implemented on this project?

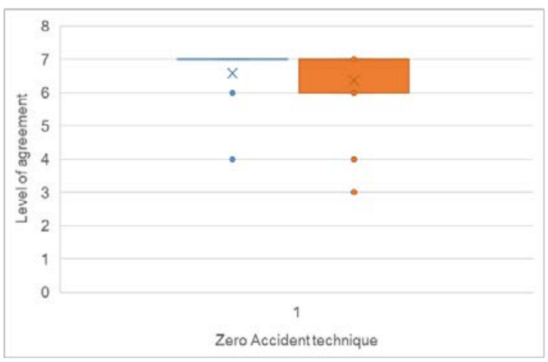
Material Management: Based on the definition, to what extent was Materials Management implemented on this project?

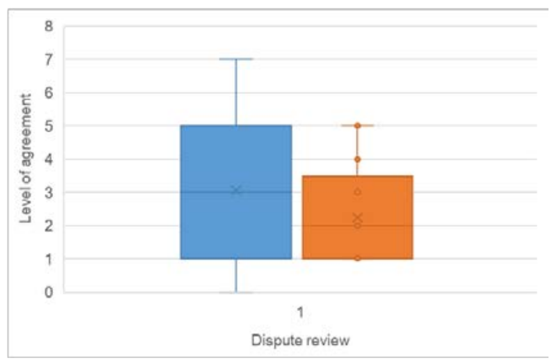




Zero Accident Techniques (i.e., Safety): Based on the definition, to what extent was Zero Accident Techniques implemented on this project?

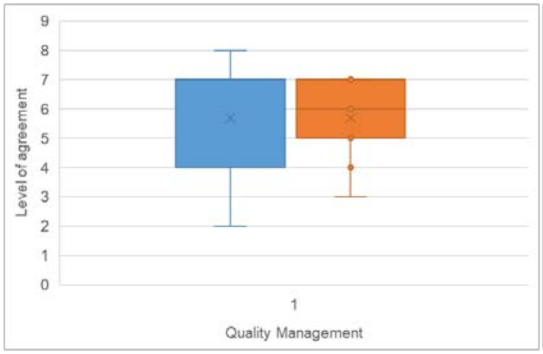
Dispute Prevention and Resolution: Based on the definition, to what extent was Dispute Review implemented on this project?

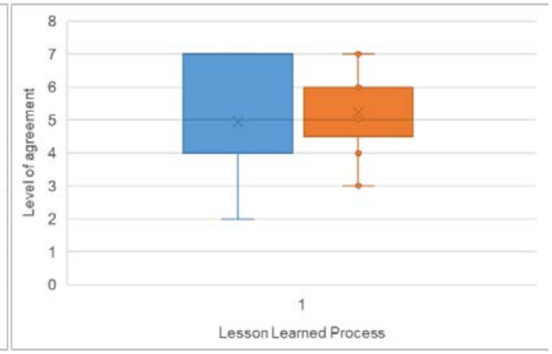




Quality Management: Based on the definition, to what extent was Quality Management implemented on this project?

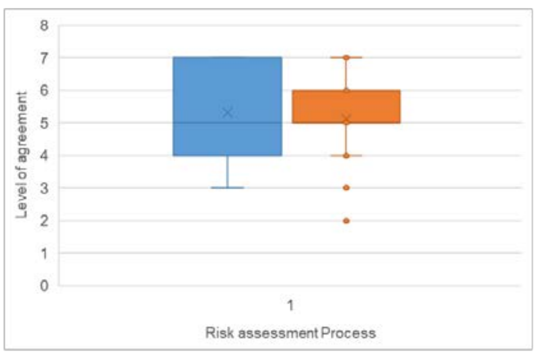
Lessons Learned Process: Based on the definition, to what extent was a Lessons Learned Process implemented on this project?

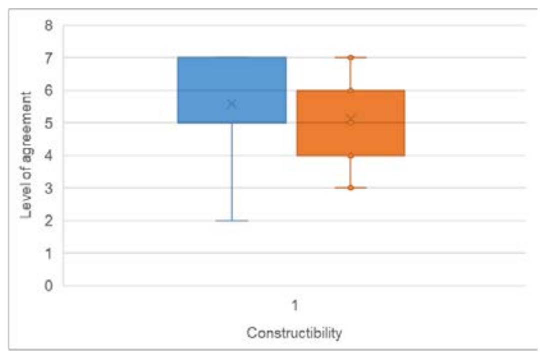




Risk Assessment Process: Based on the definition to what extent was a Risk Assessment implemented on this project?

Constructability: Based on the definition, to what extent was Constructability implemented on this project?





Appendix D

Demographic information of

the survey respondents

The table below shows the demographic information of the 44 respondents.

Years of Experience	Number	Percentage (%)	Current Role in the Company	Number	Percentage (%)
0-10	4	9	Program Director	10	22
11-20	12	27	Project Manager	30	69
21-30	14	32	Engineer	4	9
31-40	12	27			
Above 40	2	5			

Biographical Information

Mohammadreza Habibi holds his bachelor's degree in Architectural Engineering from the Shiraz University, Iran in 2013. He also earned his master's degree in Civil Engineering focusing on Construction Engineering and Management at the University of Texas at Arlington in May 2018. His research was about identifying phase-based schedule/cost performance factors and their best practices in heavy industrial projects. He was working on this topic for 16 months under the supervision of his advisor, Dr. Kermanshachi, and he published three papers during this period; one journal article and two conference papers. His article was published in Journal of Engineering, Construction and Architectural Management and his conference papers were published in Construction Research Congress (CRC) Conference, Louisiana State 2018.

Mohammadreza worked for University of Texas at Arlington as a teaching assistant (TA) for three semesters. He was the TA for *Statistics for Construction, Construction Planning and Scheduling, Construction Engineering.* During his education at the University of Texas at Arlington, Mohammadreza attended Underground Construction Technology (UCT) International Conference in Fort Worth (2017), and worked as a volunteer student. In the first semester of his studies, he also voluntarily worked in the Center for Underground Infrastructure Research and Education (CUIRE) as a researcher and designer. Mohammadreza was the recipient of 2017 Civil Engineering Endowed Scholarship from ASCE Dallas Branch.