Phase-based analysis of key cost and schedule performance causes and preventive strategies

Research trends and implications

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Abstract

Purpose – 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. Therefore, it is crucial to identify key project cost and schedule performance factors. However, despite the attempts of numerous researchers, 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. The paper aims to discuss these issues.

Design/methodology/approach – The objective of this study was primarily to identify and prioritize engineering, procurement and construction key performance factors (KPFs) and to strategize ways to prevent performance delays and cost overruns. To achieve these objectives, more than 200 peer-reviewed journal papers, conference proceedings and other scholarly publications were studied and categorized based on industry type, physical location, data collection and analysis methods.

Findings – It was concluded that both the time required to complete engineering/construction phases and the cost of completing them can be significantly affected by design changes. The two main causes of delays and cost overruns in the procurement phase are construction material shortages and price fluctuations. Other factors affecting all phases of the project are poor economic condition, equipment and labor shortages, delays in owners' timely decision making, poor communication between stakeholders, poor site management and supervision, clients' financial issues and severe weather conditions. A list of phase-based strategies which address the issue of time/cost overruns is presented herein.

Originality/value – The findings of this study address the potential confusion of the industry's practitioners related to the inconsistent list of potential KPFs and their preventive measurements, and pave the way for the construction research community to conduct future performance-related studies.

Keywords Design, Schedule performance, Cost overruns, Delay, Estimating, Construction planning, Engineering phase, Construction phase, Procurement phase, Optimization strategies

Paper type Literature review

Introduction

The construction industry is a major contributor to a nation's economy. In the United Arab Emirates (UAE), it contributes 14 percent of the gross domestic product (Faridi and El-Sayegh, 2006). It is a complex industry that is constantly changing (Lee *et al.*, 2005). From the very first stage of a project to its completion, it involves several parties, a vast range of processes with many inputs and multiple phases (Prakash and Nandhini, 2015). The success of a 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 *et al.*, 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). Since quality is abstract and difficult to define, it receives the least attention, even outside the construction industry (Mintzberg, 1982).

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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.*, 2018). Approximately 70 percent of the construction projects in the private and public sectors experience delays, with the average time overrun of 10–30 percent 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 percent, respectively (Al-Hazim *et al.*, 2017).

This study critically examines the existing research efforts related to performance and addresses the issues of time and cost overruns. The results provide a list of preventive and predictive strategies to minimize time and cost overruns during all engineering, procurement and construction (EPC) phases. Extensive research has been conducted to identify the causes behind construction performance and to devise mitigation measures, but few studies have focused on phase-based performance causes and strategies. In addition, there is no consistency in the list of key performance factor (KPFs) in the literature, as the finding of each study is different from the others. Therefore, the finding of this review, as the first study that investigates phased-based performance causes and preventive strategies, can help practitioners prevent time and cost overruns, assist them in allocating their resources and provide guidance to those in academia who are conducting research. It should be noted that this study serves as the basis for developing a survey to identify phase-based performance indicators, which will be validated through interviews.

Methodology

To fulfill the objectives of this study, over 200 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.

Research process

As is demonstrated in Figure 1, 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.

Journal name

Time and cost performance issues in construction have been examined in 32 different journals around the world, and Table I specifies the distribution of the papers according to their sources. As is indicated in this table, the first five journals listed have published the most articles on this subject (68 percent of all papers). *The International Journal of Project Management*, published in collaboration with the Association for Project Management and

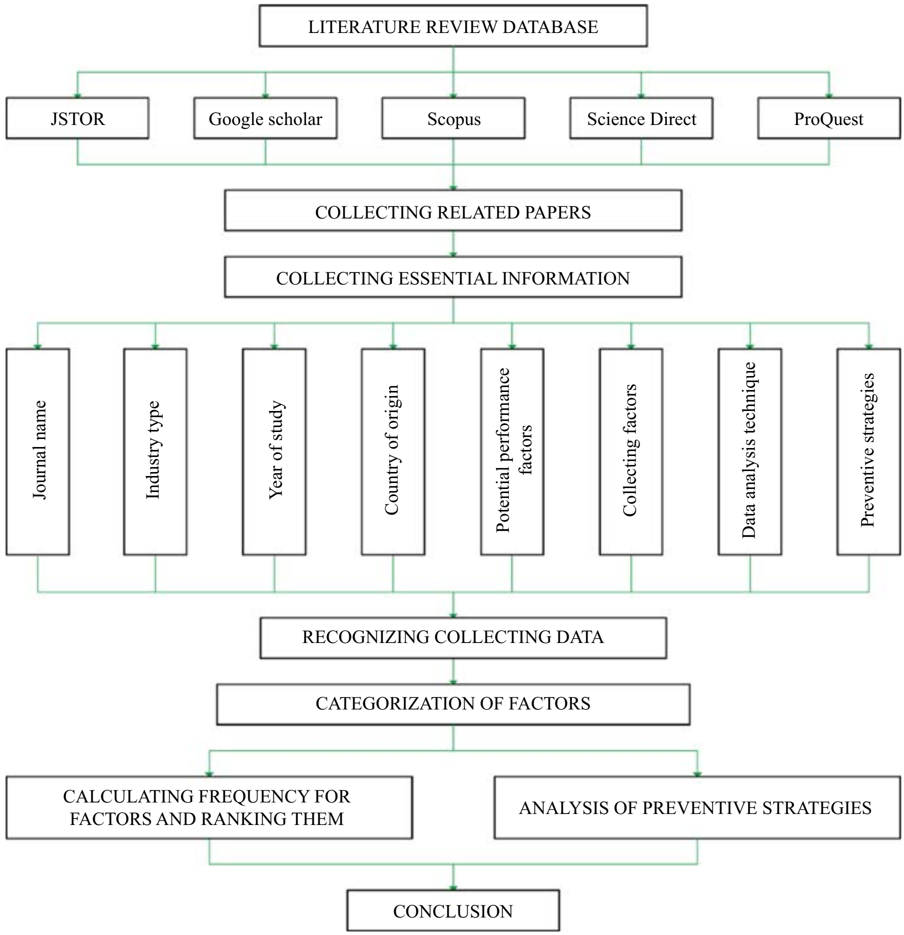

Figure 1. Research methodology figure

the International Project Management Association, ranks first with 30 papers, and accounts for 26 percent 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.

Industry type

Figure 2 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 percent. Transportation projects and underground infrastructure projects are second and third, representing 24 and 12 percent of all projects, respectively.

Year of study

As shown in Figure 3, 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,

Table I.
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[a]	20	17
Total	115	100

Note: [a]Other journals are those that have one frequency including *International Journal of Science and Management*, *Construction Economics and Building*, etc.

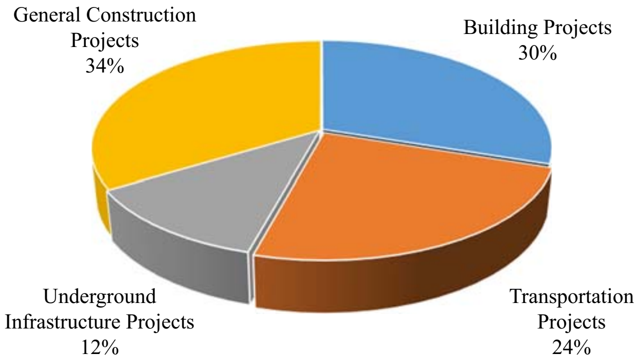

Figure 2.
Distribution of papers according to the type of projects

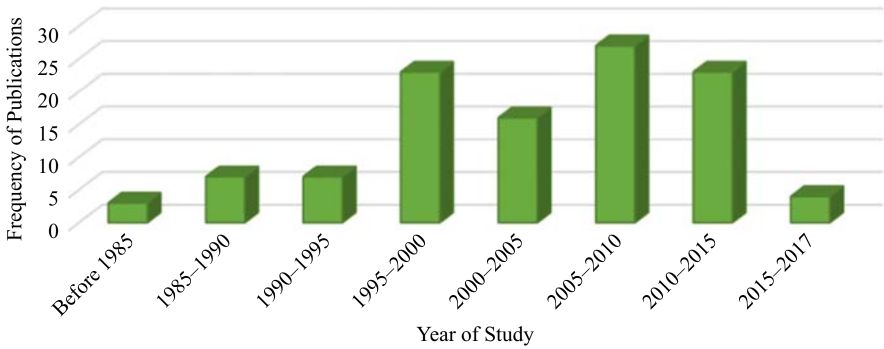

Figure 3.
Distribution of journal articles according to year of study

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.

Country of origin

Figure 4 depicts the distribution of papers according to their country of origin. Countries worldwide 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 and 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 percent 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 UAE 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, are placed third (14 percent) and fourth (13 percent), respectively. About 30 percent of all schedule/cost performance studies have been conducted in the USA, Saudi Arabia and Nigeria. The USA has the highest portion among all countries, with 12 percent of all schedule/cost performance studies. Saudi Arabia and Nigeria occupied the following positions with 9 and 8 percent, respectively.

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 interviews for large building projects in Saudi Arabia. Similarly, many researchers (Alaghbari *et al.*, 2012; 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.* 2016; 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. They included conducting pilot surveys, case studies, interviews and literature reviews. The distribution of papers according to their selected data collection practices is shown in Figure 5. 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 percent of all practices. Interviews are the next most common practice and occur in 36 percent of all practices. Case studies and pilot studies both occupy third place, with just 13 percent of all practices.

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

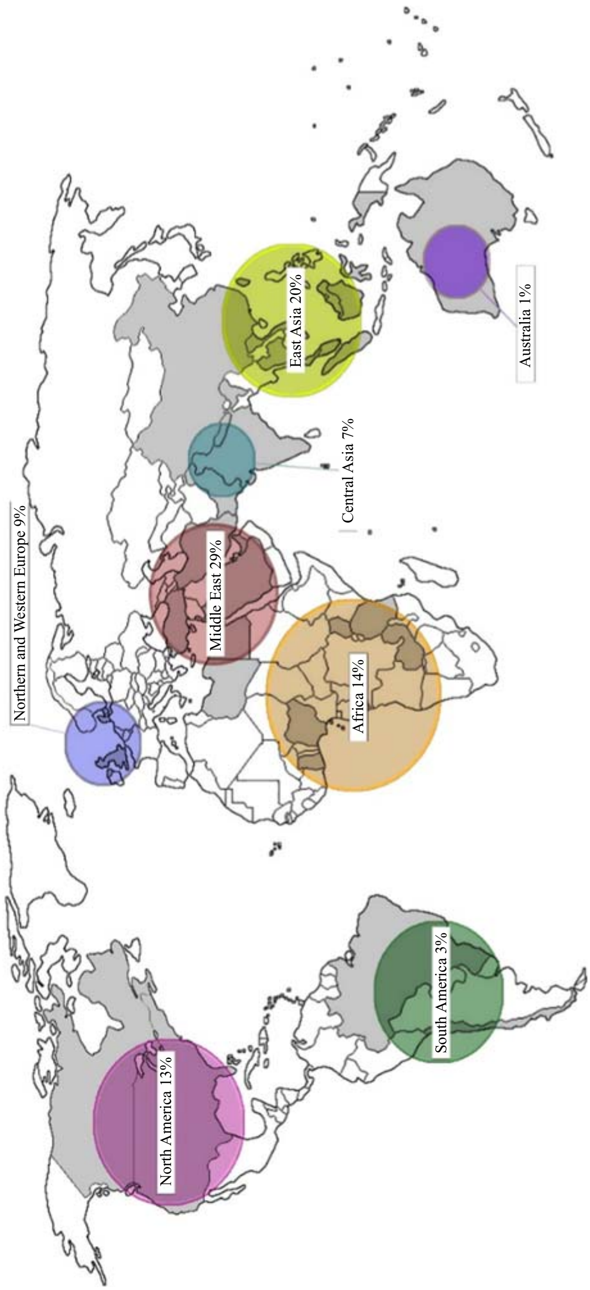

Figure 4.
Distribution of performance papers according to the country of origin

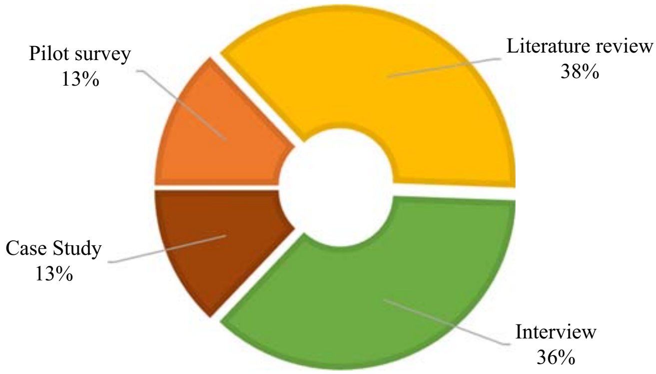

Figure 5.
Identification of performance causes

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 (FI), severity index (SI), important index (II), relative important index (RII), mean score (MS), cost performance index (CPI), regression, average relative weight, weighted average (WA), rank correlation coefficient, etc. Figure 6 indicates the distribution of utilized data analysis techniques in the identified journal papers. RII ranked first among the analysis techniques with 26 percent, followed by the severity index. II and MS were the third most common techniques, equaling 13 percent of all utilized techniques.

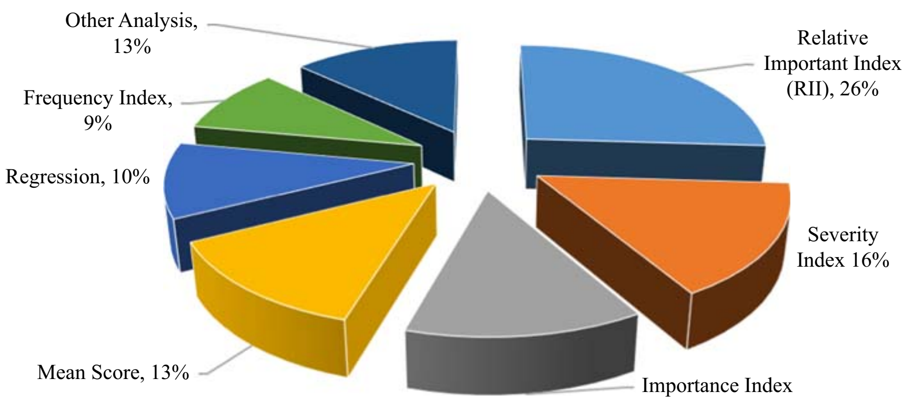

Figure 6.
Distribution of papers according to the technique of data analysis

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 four-point Likert scale ranging from 0 (never happened and no effect) to 4 (always happened and very severe). According to Asiedu and Alfen (2016), the FI and SI expressed the frequency of occurrence and the magnitude of the variables, respectively. Literature often used the RII, which is based on the SI and FI, to identify the most crucial variables (Le-Hoai *et al.*, 2008; Assaf and Al-Hejji, 2006; Asiedu and Alfen, 2016; Sambasivan and Soon, 2007; Doloi *et al.*, 2012; Megha and Rajiv, 2013; Chan and Kumaraswamy, 1997). It is computed utilizing following equations:

$$\mathrm{SI}(\%) = \sum \left(\frac{\psi_i \Phi_i}{\lambda \Omega} \right) \times 100\%,$$

$$\mathrm{FI}(\%) = \sum \left(\frac{\psi_i \Phi_i}{\lambda \Omega} \right) \times 100\% \quad \mathrm{RII}(\%) = \frac{\mathrm{SI}(\%) \times \mathrm{FI}(\%)}{100},$$

where Φ_i is the frequency of the responses of the ith rank; λ is the highest weight; Ω is the total number of responses; and ψ_i is the constant expressing the weights assigned to each of the factors by the respondents of the ith 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 five-year periods in Figure 7. 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 period (two-year period) of the last group (2015–2017), its results were combined with those of the period from 2010 to 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.

Research results

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: the planning (pre-design) phase; design phase; and

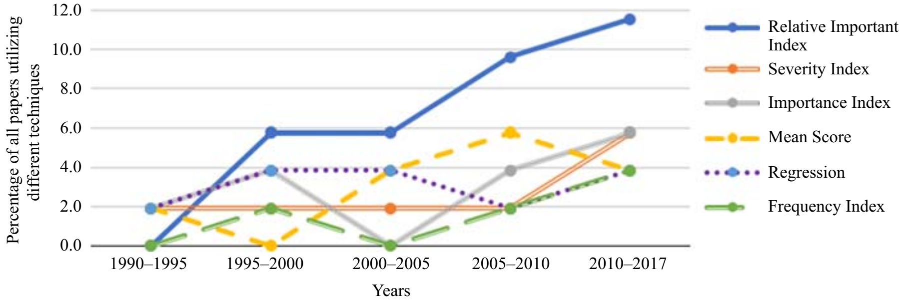

Figure 7.
Trends of utilization of data analysis techniques in published papers

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.*, 2016). 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). 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; Turner, 1984; Kermanshachi, 2016). 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.; and 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). 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 lifecycle costs of the project (Manavazhi and Xunzhi, 2001; Kermanshachi *et al.*, 2016a).

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/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 (PM) 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.

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 II. 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 *et al.*, 2017) and causes 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.

Procurement phase

While the procurement phase represents the post-engineering phase, it is also considered a pre-construction phase in EPC projects (Yeo and Ning, 2006) and is comprised of complex processes that occur in different locations (Mulholland and Christian, 1999). These processes include receiving engineering drawings from consultants, documenting and issuing requests for proposals or quotations, bidding between vendor and bidder, placing orders, fabricating and assembling equipment, testing, delivery and shipping (Yeo and 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, 1987).

Category	Key performance factors	F^a	R^b
Schedule performance factors			
Change	Design change	13	1
Client related	Slowness in making decisions	8	2
Client related	Delay in approval stage	8	2
Management	Poor communication between different stakeholders	5	3
Consultant related	Design error	4	4
Client related	Poor scope definition	4	4
Client related	Incomplete documents	3	5
Client related	Client type in terms of experience, knowledge and past performance	3	5
Management	Inadequate management	3	5
Consultant related	Late incorporation of emerging technologies (software)	3	5
Consultant related	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 related	Project size	4	2
Management	Inadequate management	2	3
Consultant related	Design error	2	3
Client related	Payment delay by client	2	3

Notes: [a]Frequency; [b]Rank

Table II. Cost and schedule performance factors in engineering phase

In addition, 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 have to be dealt with. These processes usually cause projects to face cost escalation, time overruns and inefficiency (Toor and 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, Anderson, Goodrum and Taylor, 2017; Kermanshachi, Dao Shane and Anderson, 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 and Adhikar's (2002) study, a 0.5 percent 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 such as 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 and 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 (Sambasivan and Soon, 2007; Assaf *et al.*, 1995; Mezher and Tawil, 1998). 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). 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). Using 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 and Smith (1992) mentioned, the lack of site material management can reduce daily productivity of a construction project up to 40 percent. Thomas *et al.* (2005) divided construction sites into three zones: semi-permanent, exterior storage; staging areas; and workface interior storage to address the problem of poor material management causing considerable waste in time and money.

Due to unique characteristics of the procurement phase, few factors in this phase are in common with other phases (Table III). 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 III. Cost and schedule performance factors in procurement phase

Category	Key performance factors	F^a	R^b
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 and 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

Notes: [a]Frequency; [b]Rank

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 percent 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). According to Faridi and El-Sayegh (2006), more than 50 percent of the construction projects in the 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, 2006). 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, such as 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 also 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, 2006).

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 PM 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 and Al-Hejji, 2006; 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, 2003), a study by Mahamid and Bruland (2011) concluded that 100 percent of transportation projects have cost divergence. Approximately 76 percent of the projects are overestimated, and 23 percent 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) and 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 financial stability of client, feasibility of the project, past performance of client, project characteristics and 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).

Table IV 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.

According to Table IV, 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. This factor, along with "financial issues by client," both place in the second 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.

Discussion of results

All of the cost and time performance factors in the construction industry were identified from over 200 papers and were classified into the following 13 groups: change, consultant,

Category	Factors	F^a	R^b
Schedule performance factors			
Change	Design change	28	1
Management	Poor site management and supervision	18	2
External	Severe weather condition	17	3
Finance	Financial issues by client	17	3
Common	Delay in decision making process	14	4
External	Unforeseen condition (natural disaster, etc.)	14	4
Planning and scheduling	Deficiencies in planning and scheduling	14	4
Consultant related	Delay in performing inspection and testing	13	5
Contractor related	Construction mistakes and defective work	13	5
External	Geological conditions/Terrain condition	12	6
Contractual relationship	Lack of communication and coordination between the stakeholders involved in construction	12	6
Finance	Contractors' financial difficulties	12	6
Consultant related	Design error	11	7
Finance	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 related	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 related	Delay in approval stage	7	6
Management	Contract management	7	6
Project related	Project size	7	6

Note: [a]Frequency; [b]Rank

Table IV.
Cost and schedule performance factors in construction phase

labor, client, contractor, material, equipment, external, project, management, subcontractor, 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 the frequency of occurrence of each factor was calculated from literature to find most frequent performance factors.

The distribution of the top ten KPFs in groups according to their related EPC phases and related time/cost performance is shown in Figure 8. Large portions of KPFs were distributed into the external group, indicating the importance of this group, especially in the procurement and construction phases. The majority of KPFs in the external group are 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. Management and consultant groups place in second and third positions, respectively, with management having eight factors and consultant having seven. The results of the questionnaire administered by Le-Hoai *et al.* (2008) revealed that most of the delay factors are human and/or management related. As is seen in Figure 8, client and material groups occupy the subsequent places in the order given. It should be noted that three of the thirteen groups (subcontractor, P-S-E, and contract groups) do not have any factors among the top ten ranking factors of each EPC phase.

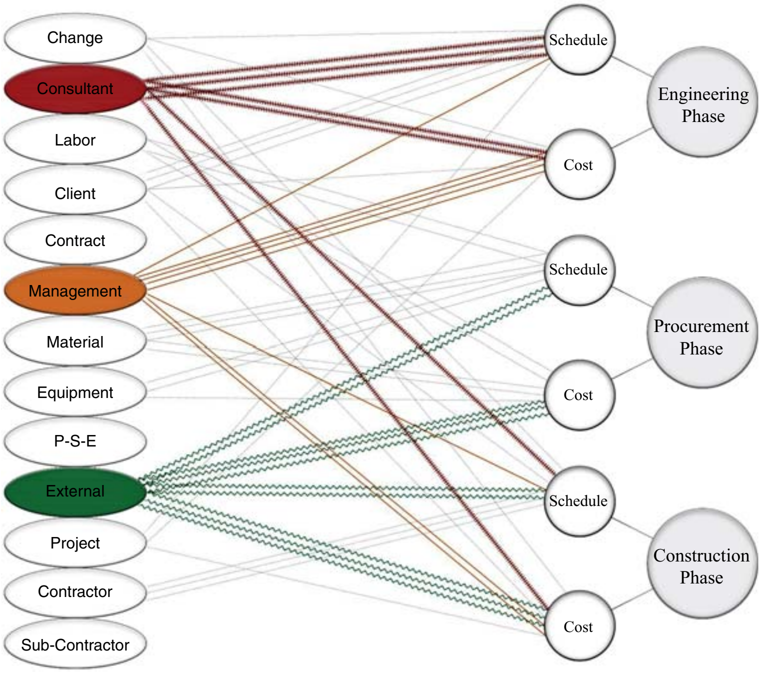

Figure 8.
Distribution of top ten KPFs in design-based performance groups

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. Despite the important role of the engineering phase in construction performance, few studies were targeted specifically at identifying the performance factors affecting this phase.

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 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 toward 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 facings reworks, cost increases and delays (Gunhan and Arditi, 2005).

Table V 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, improvements in the construction phase performance are 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 V, potential risks of delays and cost overruns in the engineering phase can be minimized when consultants allocate adequate resources to meet the client's requirement 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 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. Strong, effective information flow and management during the implementation stage can result in better time/cost performance in the construction phase.

Conclusion and future work

The construction industry strongly impacts the economy of a country, making it a popular subject of debate among construction practitioners and scholars. It suffers from inconsistent lists of schedule/cost performance factors and lack of preventive strategies to address the issues. Most previous studies focused on the construction phase since it consists of majority of construction activities. More than 200 papers were studied to identify the KPFs and their preventative strategies in the various EPC phases. These studies were based on the industry, year of study, location, data analysis techniques and data collection practices. Ultimately, the identified factors were ranked according to the frequency of their occurrence in literature to deal with inconsistency issue and then were categorized into 13 groups. The most frequent factors affecting the cost and schedule performance of each EPC phase were recognized separately, and the recommended prevention strategies have been presented in this paper. Design change was found to be the KPF having the most significant effect on the schedule/cost performance of the engineering and construction phases. It was also found that the schedule performance of procurement phase is highly affected by a shortage of resources. This factor, along with price fluctuations and poor economic conditions can increase the cost of the procurement phase. Other schedule/cost performance factors are the owner's untimely decision making, poor communication between stakeholders, poor site management and

Responsible entity	Preventive strategies	Reference
Consultant	Devote 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)
	Organize meetings between design team and submitting written progress report of initial phase at least twice per month	Kuprenas (2003)
	Utilize information-based technologies	Lee *et al.* (2005)
	Incorporate constructability practices early in the design phase	Kometa *et al.* (1994), Lee *et al.* (2005)
Client	Establish financial motivation methods for designers/engineers to eliminate potential delays and improve schedule performance	Kometa *et al.* (1994)
	Allocate adequate time and budget for feasibility studies and site investigations to avoid unanticipated circumstances in the planning phase	Mohamad *et al.* (2012)
	Provide sufficient information for owner to make right decisions which 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 and Al-Hejji (2006)
	Define proper level of funding in the planning phase leading to regular payments to the contractors and/or subcontractors based on the progress of work	Frimpong *et al.* (2003)
	Formulate a systematic contractor selection process based on project goals and needs	Lo *et al.* (2006), Kermanshachi *et al.* (2016b),
	Establish a review process to ensure all project requirements are included in the bidding documents	Lo *et al.* (2006)
Contractor	Sign blanket purchase agreement (BPA) to fill anticipated repetitive needs for supplies or services (also known as call-off order)	Alarcón (1997)
	Select local vendors to minimize transport distance	Alarcón (1997)
	Implement mandatory trainings for site labors including site-specific safety programs which creates a safe job site and prevents potential accidents	Lee *et al.* (2005)
	Hire qualified and experienced management staff to meet the project's plan requirements during the construction phase	Al-Hazim *et al.* (2017)
	Form an official material and human resource management guidelines to eliminate project inefficiencies	Okpala and Aniekwu (1988)
	Perform continuous work–training programs for office personnel to update their knowledge and learn about innovative project management techniques and processes	Frimpong *et al.* (2003)
	Execute effective material procurement to avoid potential supply delay	Frimpong *et al.* (2003)
Consultant and client	Define scope clearly and completely to minimize potential scope creep and rework	Lo *et al.* (2006)
	Establish proper design process and make appropriate time control decisions	Ahmed *et al.* (2003)

(*continued*)

Table V.
Preventive strategies to minimize/control project delays and cost overruns

Responsible entity	Preventive strategies	Reference
Consultant client and contractor	Develop shared goals, trust, commitment and accountability among team members to improve problem-solving skills of project participants	Lee *et al.* (2005)
	Settle information flow or interaction channels to address problems during implementation stage	Le-Hoai *et al.* (2008)
	Hire an independent partnering member to evaluate the conflictual situation and increase efficiency of the project	Toor and Ogunlana (2008), Safapour *et al.* (2017)
	incorporate a balanced change culture of recognition, planning and evaluation of project changes in an organization to effectively manage project changes	Lee *et al.* (2005), Safapour *et al.* (2018)
External	Outsource the required goods and qualified services	Ogunlana *et al.* (1996), Ho (2016)
	Increase labor wage rate and provide training scheme for beginners to address the labor and skill shortage problem	Ho (2016)

Table V.

supervision, client's financial issues and severe weather conditions which mainly influence engineering and construction phases.

Based on the findings of this review, the literature review and relative important index techniques were utilized, respectively, to collect data and analyze results from questionnaires. The matters of cost escalation and time overruns were found to have more frequently drawn the attention of specialties, scholars and researchers between 2005 and 2010, and developing countries in the Middle East, East Asia and Africa devoted more time to identifying the performance factors, especially in building projects.

The findings of this paper will provide industry practitioners with a consistent list of significant performance factors, allowing them to allocate their resources properly and suggest some strategies to prevent potential cost and time overruns. This review also provides construction scholars with a detailed and extensive view of EPC cost and schedule performance factors, and provides the context for future performance studies.

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