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Identifying and Measuring Engineering, Procurement, and Construction (EPC) Key Performance Indicators and Management Strategies

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Abstract: Delay and cost overrun in construction projects are two widespread problems that arouse practitioners' and scholars' concern. Therefore, the objective of this study was to identify Key Performance Indicators (KPIs) in each of Engineering, Procurement and Construction (EPC) phases separately and then calculate the weight impact that is associated with each of identified KPIs. Additionally, this study aimed to find the most appropriate Best Practices (BPs) for the identified phase-based indicators. Through a review of existing literature, a survey was developed to collect data from the completed construction projects. Various statistical methods, including two sample T-test and Kruskal-Wallis test, were utilized to analyze the data. Subsequently, Epsilon-Squared effect size method was applied to prioritize the identified KPIs. Since the lack of communication and slowness in decision making were found as the primary schedule Performance Indicators, schedule performance was identified to be highly affected by managerial approaches and actions. In addition, clients play a decisive role, because owner-driven change orders were found as the most crucial cost performance indicator affecting the performance of the engineering and construction phases. The outcome of this study helps practitioners and scholars to understand the phase-based cost and schedule KPIs, and appropriate mitigating strategies to improve the construction performance in EPC phases and save time and money.

Keywords: performance; engineering; procurement; construction; delay; cost overrun; schedule overrun; management strategies

1. Introduction

Poor construction performance has been a matter of debate among scholars and construction practitioners throughout previous decades. Due to the steady economic growth, the presence of high-level competition and rapid changes in the construction industry, many companies are forced to observe and improve their performance constantly. Moreover, it has been proved that an effective construction performance could be achieved based on the successful implementation of the three Engineering, Procurement, and Construction (EPC) phases. Notably, the performance of each EPC phase can be examined from three main perspectives: schedule, cost, and quality [1,2]. However, owing to the obscure nature of quality, it can hardly be defined and measured. Consequently, the two components of project time and cost overrun have been tied to the evaluation of construction projects' performance [3,4]. The project cost and time are important to the management team at all times [5,6]. In construction projects that are exposed to several risks, cost overrun and delays represent threats for the success of the project [7–9].

Le-Hoai et al. [10] highlighted that the unintended effect of these undesirable performances mostly become visible in the construction phase despite the fact that the causes of poor schedule and cost performance result from all EPC phases' performance. Apart from this, occupying the majority of activities of construction process makes the construction phase attract the most attention in the construction industry. Nevertheless, it does not necessarily mean neglecting the importance of other phases' performance and their effects on the success of the project. As Paulson stated, despite the small cost of the engineering phase, it has the highest effect on the total cost of the project [11,12]. Consequently, even slight deficiencies in the engineering phase can have catastrophic effects on the cost performance of the entire project [4,13].

In general, the average magnitude of cost and time overrun in construction industry depends on various project characteristics that comprise project location, project type, industry, and time of construction [14,15]. Herein, Assaf and Al-Hejji [16] concluded that 70% of construction projects exceed their initial proposed time completion, with an average of 10%to 30% in Saudi Arabia. However, the average time overrun in construction buildings of Ghana goes beyond 40% of the estimated schedule, up to the point that the public and private construction build had approximately 176% and 77% time overrun, respectively. It is of importance to identify the leading causes of poor construction performance and minimize the possible risk in order to overcome these tremendous variations.

Therefore, the objective of this study was (1) separately identify Key Performance Indicators (KPIs) in each of Engineering, Procurement, and Construction (EPC) phases; (2) calculate the weight impact that is associated with each of identified KPIs; and, (3) find the most appropriate Best Practices (BPs) for the identified phase-based indicators. Despite considerable researches that were carried out in construction performance and their key indicators, few studies investigated phase-based cost and schedule Performance Indicators. Herein, it seems that the significance of engineering and procurement phases in the literature were almost disregarded in comparison with construction phases. Apart from providing a list of the significant phase-based Performance Indicators, this study also aims to calculate and prioritize the weight impacts that are associated with the identified key Performance Indicators in each of the EPC phases. Moreover, this study aims to determine the significant construction BPs that reduce EPC cost overruns and schedule delays. The results of this research help construction experts to allocate their resources effectively and enhance their phase-based construction performance, resulting in saving money and time. The finding of this study also provides the context for academic scholars to conduct further researches and open new horizons for phase-based construction cost and schedule performance.

2. Literature Review

Since the economy is profoundly affected by the construction industry, any procrastination in the initial project schedule negatively influences the overall economy of the country [17,18]. Moreover, deviation in construction performance has become a universal phenomenon in the construction industry, mainly in developing countries, up to the point that more than half of the construction projects in the United Arab Emirates (UAE) postponed their substantial completion. Therefore, it is crucial to identify the critical Performance Indicators to fill this gap in construction and to help developing countries in order to boost their economic [4].

2.1. Project Types

Different methods can be used for project delivery, among which EPC has commonly been used in various construction markets [19,20]. This method emerged in the United States (U.S.) in 1970s and was introduced into other countries mostly after 1990s [21]. EPC includes advantages regarding the traditional Design-Bid-Build (DBB) method for providing expectations of clients, such as reducing financial uncertainties, improving project productivity, and reducing any disputes, as well as expanding the profitability of potential contractors [22]. However, as the single entity that is responsible for the delivery of international EPC project, contractors withstand massive risks from clients' side, related to both complex international environment and the activities of the project [23,24].

2.2. Factors Affecting EPC Project Performance

A vast range of researchers devoted their efforts to find the delay and cost overrun causes in the construction industry [10,25–27]. Ahmed et al. [25] prepared and distributed a questionnaire to contractors in order to discover the most decisive factors that cause a delay in building constructions of Florida. All of the delay causes were classified into six broad groups; acts of God, design-related, construction-related, management/administrative, financial/economic, and code-related. The researchers also concluded that the "code-related" category was defined as the most critical category, which the government is mostly in charge of these regulations. Similarly, Le-Hoai et al. [10,28] followed the same methodology to uncover overrun causes specifically in the construction phase. They stated that most of the causes in the construction phase could be attributed to human errors and deficiencies in management. These causes include "poor site management and supervision", "poor project management assistance", "financial difficulties of the owner", "financial difficulties of the contractor", and "design changes". Mahamid [29] also developed a questionnaire among the primary public stakeholders to get their perceptions regarding the most critical Performance Indicators in Saudi Arabia. In this study, it was found that "poor communication among project participants" and "payment delay" were the top severe factors from the owners' and contractors' points of view, respectively. Additionally, consultants believed that construction projects are mostly subjected to poor performance due to the poor planning and scheduling and poor site management.

"Design changes" is one of the most vital factors that affect construction performance, specifically in the construction phase [30]. These changes in construction projects are almost inevitable, and they usually bring excessive claims, disputes, additional work, and duplication of efforts contributing a project to experience a delay [30,31]. Similarly, Habibi & Kermanshachi [32] concluded that design changes are often responsible for deferring time completion and adding cost in both the engineering and construction phases [33]. Not only can any modifications be attributed to the design changes, but also any additions or deletions to the scope of the work can change the agreed framework in the contract.

It is undeniable that resource constraints have highly affected the procurement phase. Material shortage, lack of productive equipment, and unavailability of qualified labor and skilled technical personnel hinder construction projects from having effective performance, especially in the procurement phase [26,27,34,35]. Developing a questionnaire to evaluate the primary causes of delay in the Malaysian construction industry, Sambasivan & Soon [27] reported that the unavailability of material, labor, equipment, along with equipment failure, are among the significant causes postponing project from the proposed schedule that is specified in the contract. Imported resources is another significant performance factor mentioned in literature many times. Herein, since, in some countries, the value of the local currency is so low when compared to that of exporter countries, the exchange rate imposes many restrictions on the marketplace and, as a result, the price of imported resources is increased and it affected the overall cost of procurement phase [36,37].

2.3. Identification and Prioritization Techniques

Identifying an abundance number of schedule and cost Performance Indicators leads many researchers to seek the most significant preventative measures and corrective actions [16,30,38,39]. For instance, Olawale & Sun surveyed 250 construction project organizations in the United Kingdom (UK) and found that design changes, risks/uncertainties, inaccurate estimation of project time/duration, complexities, and non-performance of subcontractors are top five leading inhibiting factors that cause time and cost overrun in the project [40]. To overcome these five factors, these researchers proposed several mitigating measurements and classified them into four categories: preventive, predictive, corrective, and organizational measures. In the meanwhile, Ling et al. [41] conducted research regarding the best project management (PM) strategies that were adopted by Singaporean AEC firms on Chinese international construction projects [41,42]. According to their research, offering high-quality responses towards perceived variations, controlling technology transfers risks effectively, and conforming closely to contract requirements are top three PM strategies helping to achieve better performance. Several studies devoted their time to identify the positive effects of Best Practices on the overall project performance. However, Lee et al. [43,44] looked at this matter more specifically and cited the BPs, particularly focusing only on time and cost performance, including pre-project planning, project change management, and design/information technology practice. Similarly, Safapour et al. [45] explored and assessed the utilization of five essential Best Practices to reduce the schedule delays and reduce the cost of construction projects for the construction clients. These five Best Practices include team building, alignment, change management, front-end planning, and partnering.

3. Methods

A six-step research methodology was developed to achieve the objectives of this study. As shown in Figure 1, extensive research was undertaken to investigate potential KPIs and BPs in each of the EPC phases. In the second step, based on the results of the literature review, a detailed and structured survey was developed and then distributed among construction practitioners. Next, the acquired responses were tabulated, and the preliminary data analysis was carried out to qualitatively analyze the cost and schedule performance of the collected projects. In the fourth step, phase-based KPIs were identified. Subsequently, different statistical data analyses, including two-sample t-test and Kruskal-Wallis test, were performed to determine the significance level of KPIs in order to prioritize the identified KPIs in each EPC phase. Finally, the significant phase-based construction BPs for the EPC phases were identified.

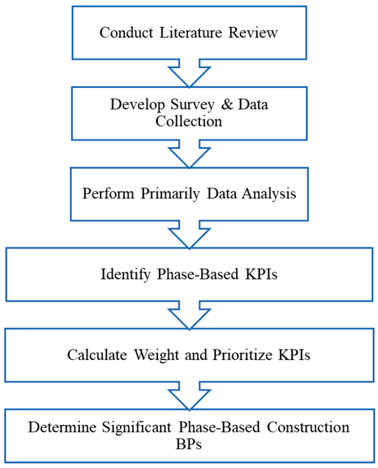

Figure 1. Research Methodology Process.

The hypothesis formulated for this study was structured, as follows:

- Null hypothesis (H0): The identified KPIs are not significant in differentiating the poor and effective cost and schedule performances.
- Alternative hypothesis (H1): The identified KPIs are significant in differentiating the poor and effective cost and schedule performances.

After categorization of the KPIs in the sixth step, in the last step, the research team transformed data in order to calculate the weights that are associated with each of the identified KPIs. Using the

Epsilon Squared Effect Size test, a weighted and prioritized list of cost and schedule KPIs for each of the EPC phases was developed. Equation (1) was utilized to compute the effect sizes.

$$E_{R^2} = \frac{H}{(n^2 - 1)/(n + 1)} \tag{1}$$

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)

4. Survey Development and Data Collection

A broad list of the potential KPIs were identified as a result of reviewing more than two-hundred journal articles, conference papers, research reports, and dissertations. Figure 2 indicates the screening process that was followed to prepare the initial list of indicators for conducting this research. As it is shown in Figure 2, since some of the identified indicators were highly similar to each other, the authors combined the similar indicators in order to narrow down the list. All in all, 121 indicators were found and classified into the relevant schedule and cost performance of each EPC phase. Subsequently, all of the KPIs were classified into 12 groups, namely Change, Management, Contract, Client & Consultant, Planning, Scheduling and Estimating (PSE), Contractor, Labor, Project, Material, Equipment, and External.

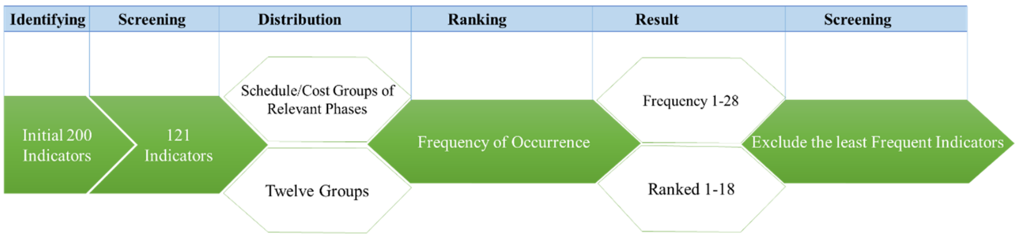

Figure 2. The screening process to prepare the initial list of indicators.

Following the categorization of indicators, the frequency of occurrence of each indicator in the literature was calculated in order to prioritize them in each EPC phase. As a variety of indicators had the same frequency, 121 Performance Indicators have been ranked, ranging from 1 to 18, in order to find the most frequent phase-based KPIs. Acquired KPIs developed a detailed survey to assess the significance level and the effect size of each indicator. Fourty-four respondents having experiences from five to above 40 years provided their input. Among the respondents, about 96 percent had more than 10 years of experience. The participants had occupations as program director, project manager, and engineer. Table 1 shows the detailed demographic information of the respondents.

Table 1. Respondents' Demographic Information.

Experience (Years)	Number	(%)	Occupation	Number	(%)
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			
More than 40	2	5			

Since the number of KPIs with a low frequency of 1, 2, and 3 was so large, it was decided to take out those indicators having a frequency with less or equal to 3 and narrowing down our list. Table 2 presents the definition of each group, along with the phases in which each category has potential KPIs.

Notably, since the client and consultant have some indicators in common, it was decided to combine both groups and put them in a single group. According to this table, all 12 groups at least have one KPI in the construction phase, while the procurement phase covers the smaller number of categories when compared to that of the other two groups. Moreover, the existence of indicators 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 the project. Additionally, the effect of external-related indicators seems to solely appear in the construction phase, but it does not necessarily mean the effect of this category in the overall performance of the project is the least.

Table 2. Classification of Performance Indicators 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					√	√

This questionnaire was designed in three sections; (1) Project general description; (2) Key Performance Indicators (KPIs); and, (3) Best practices preventing construction projects from having cost overruns and delays. Herein, a question was designed for each KPI and BP in the survey to ask respondents about the impact of them on the EPC cost and the schedule performance. Section 1, general project description, includes 20 questions asking regarding the general information and project characteristics of the examined projects, such as size, duration, contract, type, etc. of projects. Section 2 included questions that were used to collect data for analyzing KPIs. Section 3, Best Practice Implementation, consisted of 13 questions representing 13 BPs that were taken from the Construction Industry Institute (CII, 2012) and provided information about the level of best practice implementation for each project. Overall, 72 questions were provided for all three sections in two formats. Figure 3 depicted two different types of questions that were designed in the questionnaire. As it is shown, the collected responses were in the form of a continuous number or an ordinal Likert scale.

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 3. Sample Survey Questions.

Likert scale questions: Likert-type scale is a kind of rating score that is utilized to specify the 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. These questions in this study were designed based on the Likert scale with seven points to assess the level of agreement/disagreement of the respondents. For instance, question 49 in Figure 3 provides a typical example to measure respondents' agreement with a variety of statements. Each of the seven points indicates different degrees of relationship between KPIs 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 3 illustrates a proper example of the numerical question, as respondents should have provided a value for the number of funding phases that they have had from concept to project completion.

A pilot-survey was distributed among four experienced practitioners to validate the clarity of each question when the survey was fully developed. As a result, an extensive definition was added to some questions for more clarification. Eventually, the finalized questionnaire was distributed among construction experts and professionals via an online platform. They were asked to select two projects that were completed in the last three years and fill out the questionnaire based on the requested information. The questionnaire intended to evaluate the different KPIs and BPs based on the responses between poor project performance and effective project cost and schedule performance.

5. Preliminary Data Analysis

The average cost of the collected projects was $120 million, ranging from $0.4 million to $575 million. Moreover, the final duration of these projects varied from eight months to 54 months, with an average duration of 24 months. Figure 4 illustrates the phase-based baseline cost and schedule of the collected data while using the box-plot method. These box-plots demonstrate the range, maximum, minimum, and median values for cost and schedule baseline of the collected projects. As it is illustrated, the average value of construction and procurement phase was almost the same, at approximately $60 million. This average for engineering phase was about one-ninth of other groups, with around $7 million. On the other hand, the average time scheduled to complete the construction phase of industrial projects was higher than other EPC phases, being 16 months. However, the engineering and procurement phase took ten months on average to reach completion.

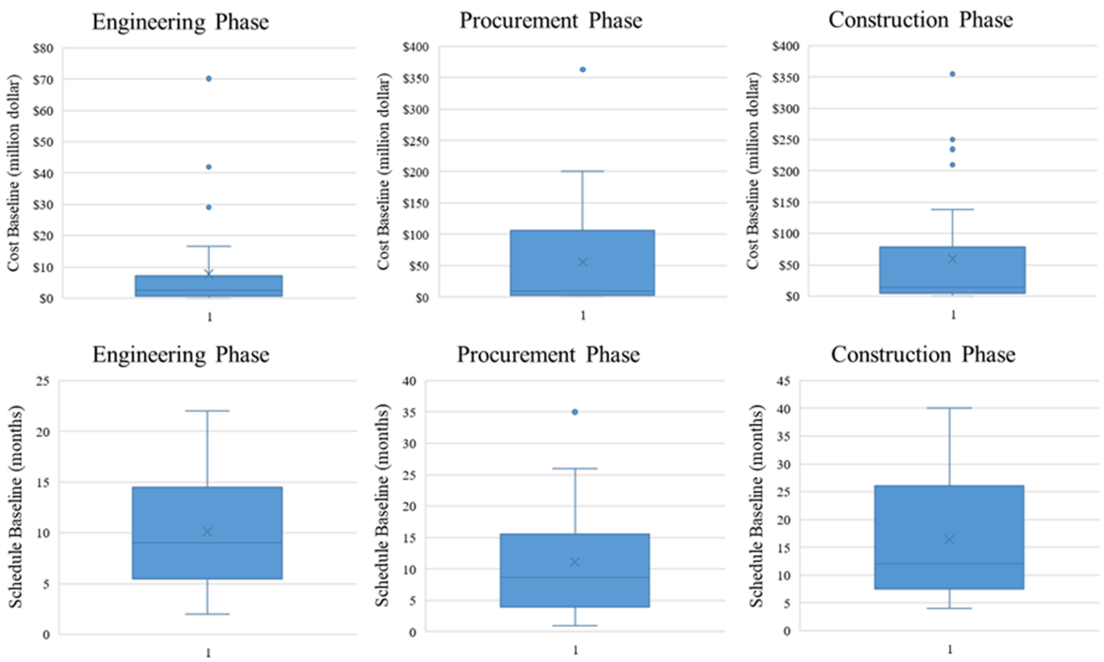

Figure 4. Phase-Based Budget and Schedule Box-Plots.

6. Results

6.1. Identification of Phase-Based KPIs

The typical magnitude of delay and cost overrun in construction projects is between 5–10% of contract duration and price of the project [46,47]. To be conservative, we decided to classify our results into two separate groups: (1) Projects with effective performance having overrun/underrun less than 10% and (2) Projects with poor performance experiencing more than 10% deviation from the cost and schedule baseline.

The results of statistical analysis (p-values) between each KPI and construction cost and schedule performance in the engineering phase were shown in Table 3. Each KPI 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 the owner", "Communication between the 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 break 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 negatively affect the schedule performance of construction. Besides, since construction is among one of the information dependent industries, a lack of communication between different construction entities causes inefficient information exchange, and therefore trust and accountability decrease. Ineffective communication also creates an atmosphere that brings disagreement and conflicts, as construction participants cannot be aligned well. Subsequently, construction projects lead to having poor performance.

Table 3. Engineering Phase Cost and Schedule Performance Indicators.

Group		Engineering Performance Indicators	P-Values	
			Schedule Performance	Cost Performance
Change	EP.1	Change order during engineering phase 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.

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 the submission of an application and required documents for each permit, the approval process is considered as a time-consuming one. In addition, the 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 the 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 KPIs were classified in "Client & Consultant" group, indicating the decisive role of these two entities in the cost performance of the engineering phase. Moreover, a curious fact is that "Change order driven by owner" is the only indicator that can significantly affect both the schedule and cost performance of the engineering phase with the p-value of "0.001" and "0.051", respectively. This could be described as the immense importance of design changes on the performance of the engineering phase; it can cause additional work that requires enough efforts and resources to be completed. Due to the nature of construction, changes in this industry are inevitable. Most of the time major changes require engineers to revise the drawings and send them for approval process again. Subsequently, the project management team should also devote more time to reschedule the project and update the client with the new estimation. Therefore, any change order to construction can deviate construction performance from the baseline schedule and the cost of the project.

Table 4 specifies the relationship between KPIs and construction performance in the procurement phase. According to this table, "Material quality", "Material shortage", "Transportation delays", "Imported labor", and "Slowness in decision making" were statistically proven to potentially affect the schedule of procurement phase. Among these indicators, "Material quality" and "Imported labor" were significant with a 95% confidence level. Particularly, if the quality of the 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, the 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 the time or their adoption to the new environment could be a challenge. Therefore, utilizing imported labor may impose many obstacles on the time and cost performance of projects.

Table 4. Procurement Phase Cost and Schedule Performance Indicators.

Group	Procurement Performance Indicators		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.

Reviewing the defined group of KPIs indicates that material-related indicators have the largest portion among the significant schedule performance indicators in the procurement phase, with three significant indicators. On the other hand, equipment-related indicators comprising "Equipment shortage", "Imported equipment", and "Equipment quality" significantly affect the cost performance of the procurement phase. For instance, the price of equipment increases because of the bloom in the economic condition of the 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 [35,40]. It may be worth mentioning that "Imported labor" and "Slowness in decision making" are the only common KPIs between the two groups, which can lead a project to experience both delay and cost overrun. Due to a higher order of qualified resources, demand may exceed supply, and because of unavailability of resources, suppliers do not offer them for a long time. Therefore, even little delay in decision making for providing resources may impose severe implications to the project goals and cause delay and cost overrun.

Table 5 illustrates the relationship between potential KPIs and construction performance in the construction phase. As it is shown, since this phase includes most construction processes, it has a greater number of KPIs affecting construction schedule/cost performance when compared to that of other EPC phases. In the meanwhile, it is realized that 11 KPIs significantly influence the time completion of the construction phase. Having eight indicators (out of 11) in "Management" and "Client & Consultant" groups indicates the significance of these two groups and their KPIs on the construction performance. One of the most crucial general indicators is the lack of communication between different entities, which itself includes three significant indicators in Table 5: "Lack of communication between prime contractor organizations", "Lack of communication between designer & contractor", and "Lack of communication between client & contractor". The "Management" group also has the largest portion of the significant KPIs in the list of construction phase cost Performance Indicators, with four indicators. This might bring to mind that a substantial portion of time and cost overrun in the construction phase can be addressed if construction practitioners apply effective managerial skills during the construction phase. Table 5 reveals that there are eight significant KPIs deviating projects from both the proposed schedule and cost in the execution stage. However, solely three of them are statistically significant, with a 95% confidence level in predicting both schedule and cost performance. These three KPIs are "Change order driven by the owner", "Slowness in decision making", and "Rework driven by the contractor". Mostly rework is prompted by poor workmanship, or accident at the site and change order results from the owner's change requirements in which are based on the condition. Each of these changes can be claimed as extra work that requires extra time and cost to be spent [48]. According to Table 5, contractor's experience was statistically found to have a significant impact in completing the project on time with budgeted cost. The p-value for schedule and cost performance is 0.088 and 0.007, respectively. The contractor might face a vast range of difficulties during the construction process owing to the complex nature of the construction project. Inadequate contractor experience creates more difficulties taking longer period to be addressed, or a contractor might undertake risky actions for solving the problems.

Table 5. Construction Phase Cost and Schedule Performance Indicators.

Group	Construction Performance Indicators		P-Values	
			Schedule Performance	Cost Performance
Change	CP.1	Change order during Construction phase driven by owner	0.002 **	0.001 **
Management	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 contractor and 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
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.

6.2. Prioritization of Phase-Based KPIs

The results of all KPIs in different EPC phases were categorized into two different groups of effective and poor performance projects. Since the impact of each significant KPIs are different on the construction performance, a statistical effect size method was utilized to weigh the impact size of each indicator. Table 6 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 the "Consultant & Client experience" and "Change order driven by the 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 KPIs in the engineering phase, as it is listed among the top three most significant KPIs of both the schedule and cost performance groups. Since this change order includes any modifications, additions or omissions to the scope of the work can significantly impose major changes on the construction performance and lead project to encounter major time and cost overruns.

Table 6. Ranking of Phase-Based Cost and Schedule Key Performance Indicators.

Significant Performance Indicators		Schedule			Cost		
		Weight	Weight Percentage	Rank	Weight	Weight Percentage	Rank
Code	**Engineering Phase**						
EP.1	Change order driven by owner	0.106	18%	R.3	0.129	40%	R.2
EP.2	Communication between design team	0.193	33%	R.1			
EP.3	Slowness in decision making	0.151	26%	R.2			
EP.6	Difficulty in obtaining design approval	0.078	13%	R.4			
EP.9	Low labor/staff productivity	0.061	10%	R.5			
EP.10	Consultant & client experience				0.141	44%	R.1
EP.11	Lack of frequency of reporting				0.032	10%	R.3
EP.13	Financial stability of client				0.019	6%	R.4
	Procurement Phase						
PP.1	Material quality	0.123	20%	R.2			
PP.2	Material shortage	0.074	12%	R.4			
PP.3	Transportation delays	0.065	11%	R.5			
PP.5	Imported labor	0.100	17%	R.3	0.086	29%	R.3
PP.8	Slowness in decision making	0.244	40%	R.1	0.019	6%	R.4
PP.11	Equipment shortage				0.096	32%	R.1
PP.12	Imported equipment				0.094	31%	R.2
PP.13	Equipment quality				0.004	1%	R.5
	Construction Phase						
CP.1	Change order driven by owner	0.067	9%	R.4	0.093	12%	R.4
CP.2	Slowness in decision making	0.003	0.4%	R.9	0.004	1%	R.10
CP.3	Lack of communication between prime contractors	0.159	22%	R.1			
CP.4	Lack of communication between designers and contractors	0.091	13%	R.2	0.102	13%	R.3
CP.7	Lack of communication between client and contractor	0.083	12%	R.3	0.075	10%	R.6
CP.8	Construction site layout problem				0.123	16%	R.2
CP.13	Payment modality				0.009	1%	R.10
CP.17	Rework driven by consultant	0.022	3%	R.7	0.018	2%	R.9
CP.18	Inadequacy of site inspection	0.032	5%	R.6	0.033	4%	R.8
CP.19	Consultant & client experience	0.093	13%	R.2			
CP.20	Financial stability of client	0.014	2%	R.8			
CP.25	Contractor experience	0.093	13%	R.2	0.137	18%	R.1
CP.27	Rework driven by contractor	0.053	7%	R.5	0.029	4%	R.8
CP.28	Shortage of skilled (technical) personnel				0.052	7%	R.7
CP.32	Material shortage				0.081	11%	R.5

According to Table 6, "Slowness in decision making" has the highest impact on schedule performance of procurement phase and it is ranked as the first among the list of key schedule Performance Indicators, with 40% effect size. On the other side, "Equipment shortage" and "Imported equipment" are the primary causes of cost overrun in the 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 the schedule and cost list, with 17% and 29% effect size, respectively.

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

Table 7 illustrates the total effect size of each category in different EPC phases regarding the 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 the engineering and procurement phases. In the meantime, not only is there a zero effect size of management category on cost performance of the engineering phase, but it also has minimal effect size on the cost performance of the procurement phase. The existence of managerial indicators in almost all phases reveals that construction management should be implemented from scratch to the substantial completion of the construction phase in order to save construction professionals enough money and time.

Table 7. Distribution of Significant Key Performance Indicators (KPIs) 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%

According to Table 7, "Client & Consultant" occupies a dominant role in the cost performance of the engineering phase, as it has 60% of total weight percent. In addition, the important role of the "Change" category in deviating schedule and cost performance should not be neglected, as it can affect the schedule and the cost performance of both the engineering and construction phases. The "Change" category impacts the cost performance of the engineering phase with the accumulated weight of 40%. Regarding the Procurement phase, as it is expected that resources groups have the highest weight percentage. In the meanwhile, "Material" and "Equipment" categories have more impact in comparison with that of other groups in the schedule and cost performance of the procurement phase, respectively. "Material" holds 43% of total weight percentage of schedule performance, followed by "Management" and "Labor" in the order that is mentioned in procurement performance. Furthermore, due to 64% effect of "Equipment" on the cost performance of the procurement phase, the responsible entity should adopt policies to minimize equipment-related issues and save money. Concerning the construction phase, it should be noted that "Management" places the first position in both schedule and cost performance of the construction phases, with 47% and 40% of total percentage weight. It is followed by "Client & Consultant" and "Contractor", respectively, in the schedule list, with each of them having approximately one-fifth of total percentage weight.

6.3. Determine Significant Phase-Based Construction BPs

This study concentrates on the implementation of thirteen CII Best Practices, which helps construction projects to have better performance regarding their cost and schedule [1]. These BPs consist 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. As previously mentioned, a question was designed for each BP by a seven-point Likert-scale and was provided in the survey. It should be noted that those BPs that were not applicable to a specific phase were excluded from the analysis. As a result of statistical data analysis, significant BPs improving the performance of each stage of the construction process were found and are presented in Table 8. "Material Management" and "Planning for Start-Up" were excluded from the engineering phase, as they are related to the material and equipment that are used in the construction and procurement phases. "Zero Accident Techniques" is also not applicable to the engineering phase, since it is associated to the site safety program and project environment.

Table 8. Significance Level of each Best Practices with all Engineering, Procurement, and Construction (EPC) Phases.

	Best Practices	P-Values					
		Engineering Phase Performance		Procurement Phase Performance		Construction Phase Performance	
		Schedule	Cost	Schedule	Cost	Schedule	Cost
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	Project Risk Assessment	0.147	0.082 *	0.873	0.202	0.063 *	0.084 *
5	Partnering	0.055 *	0.068 *	0.068 *	0.078 *	0.060 *	0.083 *
6	Quality Management	0.260	0.077 *	0.067 *	0.068 *	0.077 *	0.071 *
7	Lessons Learned	0.093 *	0.062 *	0.083 *	0.117	0.068 *	0.090 *
8	Front End Planning	0.048 *	0.822	0.091 *	0.077 *	0.022 **	0.118
9	Change Management	0.097 *	0.065 *	0.313	0.165	0.089 *	0.029 **
10	Dispute Prevention	0.832	0.604	0.200	0.718	0.047 **	0.094 *
11	Material Management			0.087 *	0.080 *	0.095 *	0.081 *
12	Planning for Start Up			0.149	0.324	0.427	0.497
13	Zero Accident Techniques					0.027 **	0.073 *

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

According to Table 8, it is found that all BPs, except "Planning for Start-Up", have a significant effect on the schedule performance of the construction phase. A few BPs were found to statistically impact the engineering and procurement phases when compared to the construction phase. Regarding the engineering phase, there are five BPs that can improve both the schedule and cost performance, including the Constructability, Alignment, Partnering, Lessons Learned, and Change Management. The implementation of Constructability as a BP would be beneficial in plan development, specifically when the project management team faces improper work experiences. Additionally, when the project team encounters difficulties while planning and designing a project, Constructability is a useful strategy to improve the cost/schedule performance. The utilization of Alignment strategy is suitable by reducing challenges among partners. Alignment effectively advances stakeholders' communication, since this strategy adopts a common template for the collaborators while communicating. This leads them to achieve the goals of the project within its scope with less corresponding costs.

In the procurement phase, Partnering, Quality Management, Front End Planning, and Material Management were the four BPs that simultaneously enhanced the performance of schedule and cost. Quality Management implementation constitutes periodic control and evaluation of the historical data to identify and correct error and deficiencies. This strategy assists in taking the corrective actions at the appropriate time. For example, when several teams are involved in a phase of a project, Quality Management helps to reduce the number of errors, which increases the performance of the project with regard to schedule and cost. As shown in Table 8, the Front-End Planning strategy utilization leads the project team to specify the goal and scope of the project early enough to decrease the late design and technical specification modifications. Additionally, this BP makes the schedule and cost of a project more reliable by creating a comprehensive finance strategy. In the construction phase, except for Front-End Planning and Planning for Start-Up BPs, the other ones were identified to improve the phase-based cost/schedule performance. Project Risk Assessment implementation is strongly recommended, specifically when the members of the project team do not have the required skills. In a construction project, Risk Assessment decreases the number of design changes and modifications by providing a basis to establish monitoring, training, and auditing. For instance, implementing Risk Assessment is advantageous when various localities are involved in the construction phase of a project by establishing periodic controls. Implementation of the Lesson Learned strategy improves the schedule and cost performance when laborers working in a project are multicultural.

7. Implementation of the Results

To verify this research results, two heavy-industrial case study projects were selected and implemented to measure the cost performance in their construction phase. Table 9 shows the general information of the case study projects. The baseline budget of the construction phase of each of the two projects was approximately $173 and $274 million and the baseline schedules of the construction phase for the first and second projects were 90 and 52 months, respectively.

Table 9. General Information of the Case Study Projects.

Project	Project Type	Baseline Budget of Construction Phase ($)	Baseline Schedule Construction Phase (Months)
1	Heavy Industrial	173,896,070	90
2	Heavy Industrial	273,550,000	52

As shown in Table 10, the cost overrun in the first and second case study projects were 27% and 9%, respectively. This demonstrates that the actual cost of project 1 exceeded the baseline budget more than project 2; thus, the cost performance in project 2 was higher than project 1. The further number of the existing KPIs in the first project when comparing the second one, six against two, confirms the above deduction. As a matter of fact, a greater number of existing KPIs in project 1 leads to more cost overrun and a consequently lower level of cost performance and vice versa. In addition, less contractor experience (CP25), increasing number of change orders (CP1), material and skilled personnel shortage (CP32 and CP28), extra reworks (CP18), and slow decision making (CP2) in project 1 cause three times more cost overrun when compared to project 2.

Table 10. Information for case study projects for implementation of results.

Project	Existing Cost KPIs	Cost Overrun
1	CP25: Contractor experience CP1: Change order driven by owner CP32: Material shortage CP28: Shortage of skilled (Technical) personnel CP18: Rework Driven by Contractor CP2: Slowness in decision making	27%
2	CP4: Lack of communication between designers and contractors CP18: Rework Driven by Contractor	9%

8. Contribution of the Study

This study aimed to identify the EPC KPIs, weigh the KPIs, and determine the significant construction BPs, which reduce EPC cost overruns and schedule delays. The results of this research help construction experts to allocate their resources effectively and enhance their phase-based construction performance, resulting in saving money and time. The finding of this study also provides the context for academic scholars to conduct further researches and opens new horizons for phase-based construction cost and schedule performance. The outcome of this study can be also used as the input for the development of a decision-support tool assessing the cost and schedule performance assessment of industrial projects during the very early phases. It also helps to identify projects that are more prone to delays and cost overruns and adopt effective strategies to overcome potential later challenges.

9. Conclusions

The objective of this research was to identify the phase-based KPIs that are responsible for construction time and cost overruns and calculate the weight impacts that are associated with these indicators in addition to identifying mitigating strategies to improve the construction performance in EPC phases and save time and money. This study concluded that "Change Order Driven by Owner" is the most important key performance indicator leading engineering phase performance to encounter delay and cost overrun. It was also found that "Lack of Communication between Design Team" and "Slowness in Decision-Making" considerably impacted the schedule performance of the engineering phase. On the other hand, "Consultant & Client Experience" was concluded to have a major effect, specifically on the cost performance of the engineering phase. Concerning the construction phase, it was deduced that "Contractor Experience" is the top weighted KPI influencing both the schedule and cost performance of the engineering phase. However, the construction schedule performance itself is highly affected by "Lack of Communication between Prime Contractor Organizations". Regarding the procurement phase, although material-related and managerial KPIs have the highest impact on overrunning the time, it was found that the equipment-related indicators extremely impacted the cost performance of this phase. In the meantime, "Equipment Shortage" and "Imported Equipment" were found as the most determinant KPIs leading the procurement phase to deviate from the budgeted cost. Reviewing the schedule performance of the procurement phase, "Slowness in Decision-Making" have the highest impact on all of the significant indicators. In addition, BPs for top-ranked phase-based KPIs were identified for the engineering, procurement, and construction phases separately. BPs that could improve both the schedule and cost performance of each EPC phase were identified to be more effective strategies.

One limitation of this study is that the number of respondents from the questionnaire was limited to 44, which is small in number but enough to make a conclusion. Furthermore, since some of the respondents did not answer a few questions in the survey, there was missing data in the collected raw data. Academic researchers can examine the effect size of different significant BPs on the specific indicators and prioritize them. For future studies, it is recommended to focus on KPIs during the late phases rather than early in the project. The findings of this study create a comprehensive framework for academic researchers to carry out further studies.

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