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Early-warning performance monitoring system (EPMS) using the business information of a project

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Abstract

An early-warning performance monitoring system (EPMS) is proposed to objectively measure and monitor the performance of a project for early detection of inherent poor performance problems. The EPMS is built based on project progress data and consists of a database of business information, an optimized theoretical model used as a performance measurement baseline, and an index for monitoring and forecasting the performance. By monitoring the performance through an application of the EPMS to the Korean construction project, the quarterly variation of index was found to differ by project type. These results could explain the environmental changes in the project execution. Therefore, the EPMS is expected to be an alternative for objective performance monitoring and forecasting while applying the existing methods is difficult because of the limited available data on performance indicators. The development procedures may also be useful to researchers interested in approaches to quantitatively analyze trends in various industries.

Keywords: Performance monitoring and forecasting; Early-warning system; Performance measurement baseline; Performance index; Construction project types

1. Introduction

As Peter Drucker mentioned in the expression "If you cannot measure it, you cannot manage it," performance measurement has been evaluated as a prerequisite for establishing an effective project management plan (Yu et al., 2007; Jeon and Yu, 2012). Various sectors, ranging from manufacturing to cutting-edge industries, are paying attention to performance monitoring based on objective measurement results as a key method of achieving the goals of project-participating organizations because of the complex and competitive changes in the project execution environment (Abdul-Rahman et al., 2011; Samoilenko and Osei-Bryson, 2013). Reflecting these trends, a growing interest in ways to detect early poor performance problems, which may obstruct the successful project execution, has been observed (Haji-Kazemi and Andersen, 2013; Kim, 2017).

The performance of a project can be monitored in various ways, from standards published by organizations, such as the Project Management Institute (PMI) and the Global Alliance for Project Performance Standards (GAPPS), to methods, such as the key performance indicator (KPI), benchmarking and metrics (BM&M), and earned value management system (EVMS). Among these standards, the PMI set of guidelines and standard known as the Project Management Body of Knowledge (PMBOK) provides common knowledge according

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to the life cycle, from initiation to closing (Bredillet et al., 2015). In addition, GAPPS, which focuses on clarifying the global standards of project management practices, has developed a framework of performance-based standards (GAPPS, 2007; Hyman, 2016). The UK and USA, which are the leading countries in project management, have implemented methods, such as the KPI, BM&M, and EVMS, to objectively measure and monitor project performance (Bassioni et al., 2004; Cha and Kim, 2008). KPI and BM&M are implemented by specialized organizations (i.e., Constructing Excellence (CE) and the Construction Industry Institute (CII)) providing published measurement results that can be benchmarked at regular intervals using credible data on various performance indicators (Hwang, 2008; Kim et al., 2009). EVMS was proposed based on the PMBOK, being a baseline and index result that objectively monitors performance by simultaneously considering project cost and schedule (Kim, 2010; Ichsan, 2010). Thus, stakeholders can use existing standards and methods to properly monitor the performance of an ongoing project and as preliminary information to make decisions for a successful project execution.

However, existing standards and methods have limitations when applied to performance monitoring when collecting credible data on the indicators is difficult because of the following situations: (1) conservative stance of the stakeholders on the disclosure of information caused by the recognition that the data of performance indicators, such as cost, are directly linked with the business secret (Yoo and Kim, 2015; Kim, 2017) and (2) absence of specialized or non-governmental organizations responsible for continuous performance measurement and monitoring of projects. In other words, sharing performance indicator data to implement existing standards and methods lacks consensus. In this situation, performance monitoring based on progress information may be a reasonable alternative to track the project performance with limited available data. Progress, which is defined as the percentage of work completed based on the budget, has traditionally been used to measure this performance (Barraza et al., 2000). Furthermore, the GAPPS framework sets progress as a critical management element, providing detailed performance criteria (GAPPS, 2007).

This study proposes an early-warning performance monitoring system (EPMS) using progress data to quantitatively measure and monitor the performance of projects on the macroscale and provide an early detection of the inherent poor performance problems. The EPMS is an improvement over the results presented by Kim (2017) and comprises (1) a database containing information, such as the progress and contract amount, (2) an optimized theoretical model used as the performance measurement baseline, and (3) an index for quantitatively tracking and monitoring variations in the performance. The optimized model and index are estimated based on the database of disclosed information for over 20 years. Therefore, the changes in the performance trends can be estimated by considering the inherent characteristics of the project based on the historical execution process.

This paper is organized as follows: first, the existing studies, standards, and methods related to performance measurement and monitoring are reviewed, and implications that should be considered for EPMS development are derived; second, the EPMS components are derived from the abovementioned implications, and the overall development process is presented; third, the procedures for the database construction are presented, such as data collection, refinement, and preprocessing; fourth, the growth curve and a genetic algorithm are used to present optimized theoretical models that can be used as a performance measurement baseline; fifth, the results of estimating the index to quantitatively monitor and forecast performance are presented, and the analysis is conducted in relation to the results and the market trend; and finally, the obstacles and the implications during the development process are discussed along with future improvements of the EPMS.

2. Review of existing studies, standards, and methods

2.1. Literature review

Previous studies were reviewed to consider various aspects (e.g., to examine existing standards and methods for monitoring the project performance, derive key performance indicators, set the performance measurement baseline, and suggest a system and framework for quantitative performance monitoring).

With regard to the existing standards and monitoring methods, Shin and Kim (2001) investigated the performance measurement methods of construction projects in the UK and Australia and suggested items, problems, and constraints that should be considered for adoption in Korea. Bassioni et al. (2004) reviewed performance measurement methods, such as KPI, Balanced Score Card (BSC), and the European Foundation for Quality Excellence Model. They identified the gaps in knowledge and practice when these methods are applied to UK construction firms. Yang et al. (2010) comprehensively reviewed previous studies that were generally related to performance measurement. They derived a performance measurement framework and research techniques mainly used in the construction industry. Crawford (2013) introduced the overall GAPPS standard and discussed its development direction (e.g., through a combination with other project management standards). Bredillet et al. (2015) reported the philosophical implications of a manager's competence on performance achievement through a review of the existing standards. Hyman (2016) proposed an international framework to support the successful implementation of global projects through a contrastive analysis of project management standards. Rehacek (2017) conducted a comparative analysis of general project management standards and presented directions for their application and usage.

Previous studies also made various attempts to establish key indicators for project performance measurement and monitoring. Yu et al. (2005) derived the key indicators needed to develop a performance measurement system for construction projects in Korea. Cha and Kim (2008) defined the performance indicators of construction projects and a calculation formula for a quantitative evaluation. They verified their work through expert consultation and survey. Jeon et al. (2010) and

Jeon and Yu (2012) proposed a new approach for aggregating performance indicators using fuzzy theory and the utility function to quantitatively evaluate the project performance.

As regards studies on the establishment of a baseline to evaluate project performance, Barraza et al. (2000, 2004) presented a stochastic model that used a progress-based S-curve to set the baseline for measuring and monitoring project performance. They then verified the forecasting results of the proposed model. Lee (2008) reviewed the theory of management baseline setting, which is the core principle of performance measurement using an EVMS, and suggested a method of establishing the performance measurement baseline for owners. Abdul-Rahman et al. (2011) presented a suitable performance monitoring method based on the earned value analysis for the construction industry in Malaysia.

With regard to the performance monitoring system and framework, Park et al. (2004) used a BSC to derive the key performance indicators from four perspectives: financial, growth, internal efficiency, and improvement and learning. They presented a performance measurement model based on their results. Cheung et al. (2004) proposed a web-based construction project performance monitoring system that can measure performance in the categories of people, cost, time, quality, safety and health, environment, client satisfaction, and communication to support project managers in exercising project control. Yu et al. (2007) proposed a comparable system consisting of an implementation model and a practical methodology to qualitatively and quantitatively measure the performance of Korean construction companies. Luu et al. (2008) presented an approach toward performance measurement by integrating BSC and strength, weakness, opportunities, and threats (SWOT) analysis, which they validated through a case analysis of a large contractor in Vietnam. Kim (2010) proposed a system for measuring the performance of mega-construction projects by integrating the cost, schedule, and risk. Arashpour et al. (2016, 2017) conducted an empirical research on the risks that may arise from uncertainties in on- and off-site activities of hybrid construction projects and presented practical implications to improve the performance measures and conceptual framework for the verification of seven projects in Australia. Lee et al. (2011) suggested a program performance management framework for public clients to successfully execute mixed-use development projects. Cha and Kim (2013) proposed a system for forecasting the performance of construction projects and quantitatively modeling the performance framework. Haji-Kazemi and Andersen (2013) emphasized the need for the early-warning concept and suggested a performance measurement system that uses key indicators for oil and gas projects. Ngacho and Das (2014) proposed a framework for evaluating the performance of Constituency Development Fund construction projects in Kenya.

2.2. Existing standards and methods

With regard to standards, PMBOK is recognized as a fundamental reference for project management. It consists of a project management framework and a knowledge area with the following characteristics: (1) the framework consists of the context and project management process, with the latter presenting the critical management factors according to five phases from initiation to closing; and (2) the knowledge area is divided into nine project management areas (i.e., integration, scope, time, cost, quality, and risk), with detailed processes being presented for each area. Furthermore, it proposes a project management process map that links these phases and knowledge areas and emphasizes earned value management for integrated project management (Ichsan, 2010; Rehacek, 2017). GAPPS is a unique alliance composed of government and professional associations, along with corporations and academic institutions, which was established in 2003 to create a standard applicable to common global project management (Crawford, 2013; Bredillet et al., 2015). The GAPPS standard provides a map that can be compared with competing standards for project, program, and portfolio management. The map is configured to compare the contents of the other standards, and comparisons are made according to the following six dimensions: (1) stakeholder relationship management, (2) management of project plan development, (3) project progress management, (4) product acceptance management, (5) project transition management, and (6) evaluation and improvement of project performance (GAPPS, 2007).

The details of the three methods used to monitor the construction project performance, namely KPI, BM&M, and EVMS, are as follows:

(1) KPI was developed as part of the Rethinking Construction movement in 1998 to improve the efficiency, productivity, and competency of the UK construction industry. It was established by the Construction Industry Board, the Department for Transport, Local Government, and Regions, and the Construction Best Practice Programme and has been operated by CE since 2004 (Bassioni et al., 2004). It is used to evaluate the economic, social, and environmental aspects of project performance. Companies and organizations can quantitatively identify project performance using the annual UK Industry Performance Report and a wallchart. Using the benchmark score provided by the chart, stakeholders can quantitatively assess the achievement of performance indicators measured for the overall construction industry. Therefore, they can generally determine the project performance, with these results being used as basic data for establishing a future business portfolio. The UK continues to monitor the performance of its construction projects and distributes the best practices based on KPI. Hence, an improved performance compared to 1999 was reported in 2015 in terms of the duration and cost compliance ratio (Kim, 2016).

(2) BM&M is a performance measurement method developed by the CII in the US to increase the value of the construction industry and enhance its capacity to execute construction projects by identifying the best practices for a wider application (Cha and Kim, 2008). The CII collects project information from members comprising

owners and contractors, suggests the norm for measuring performance and quarterly measurement results, and provides best practices based on project and industry information (Hwang, 2008). The database constructed to implement this method is composed of information on a total of 1947 projects, and the entire business scale is reported to be more than US $194 billion (CII, 2011). The performance indicators are divided into general indicators that have been in use since the time of development and indicators of specialized projects according to member needs. The indicators mainly evaluated in the context of a construction project are included among the general indicators (i.e., cost, schedule, change, rework, and safety)) (Kim et al., 2009). The performance monitoring results obtained using BM&M are announced quarterly. The distribution of best practices through this approach has been reported to have a positive effect on the scheduling and costs for clients and contractors (CII, 2011).

(3) EVMS is a performance measurement and monitoring method that supplements the cost/schedule control system criteria of the US Department of Defense. The results are determined from the cost and the work breakdown structure, and quantitatively determining the actual input cost and progress compared to the plan is possible using a baseline and cost/schedule performance index (Ichsan, 2010). The application of EVMS to projects provides advantages, such as objective performance measurement encompassing schedule and cost and notification of whether the project expenditure exceeded the budget upon completion (Kim, 2010).

2.3. Implications

Previous studies set various research scopes, introduced alternatives for monitoring project performance, and emphasized methods for early detection of poor performance. In addition, the existing standards and methods provide management guidance related to performance indicators and methods or baseline and quantitative results based on data collected through the supervision of specialized organizations. In summary, baseline and quantitative results must be established based on credible data to objectively monitor project performance.

However, applying existing standards and methods is difficult in the situation, where the available data for performance monitoring are limited because of the conservative stance of stakeholders regarding the disclosed information related to the performance indicators and the absence of dedicated organizations. The authors set the following research questions to develop an alternative that can be used to measure and monitor the performance in the abovementioned situations: (1) Is it possible to gather credible data that can replace the existing performance indicators? (2) Is it possible to deduct a method of deriving the quantitative results provided by existing methods? (3) Is it possible to derive the forecastable results that can detect early the poor performance problems considering the inherent characteristics of projects?

Targeting these aims, we worked to derive a baseline and an index based on historical progress data recorded over a period of approximately 20 years through the Data Analysis, Retrieval, and Transfer System (DART) in Korea. DART is operated by the Financial Supervisory Service, which is a government-affiliated entity. The disclosed data are provided in accordance with relevant laws and regulations, such as the Financial Investment Service and Capital Market Act. The listed corporations are obliged to enter their project and business results into DART each quarter. They will be subjected to financial and legal sanctions if they do not comply with the disclosure requirements. Thus, credible data can be collected through DART to monitor the project performance. Accordingly, this study fills the research gap described earlier by suggesting a standardized analysis framework using credible data that can be applied to the situations, where available information is limited for performance measurement and monitoring. This is achieved by benchmarking the elements being actively utilized to monitor the project performance, rather than compensating for the limitations or weaknesses of the existing methods. In addition, this study presented the results that can support performance monitoring according to the project type based on the disclosure data collected in the Korean construction industry recognized as one of the representative national key industries.

3. EPMS components

The EPMS components set considering the abovementioned implications are as follows: (1) a database related to business information on construction projects in Korea, (2) a theoretical model used as a performance measurement baseline, and (3) an index for monitoring the construction project performance. Fig. 1 shows the EPMS development process, and the details are presented below.

First, the existing studies and methods use various indicators to measure and monitor the construction project performance. However, collecting credible data for performance indicators, such as cost and duration, is difficult in Korea because of the conservative perceptions of stakeholders on information disclosure (Yoo and Kim, 2015; Kim, 2017). Thus, this study constructed a database using business information for a 20-year period from DART as an alternative. The database was constructed by adding detailed project information, followed by organization, refinement, and preprocessing.

Next, the existing methods apply the concept of best practice as a baseline to monitor the performance of the construction projects. Thus, a baseline must be established to objectively measure the performance of a construction project. Therefore, the growth curve and a genetic algorithm (GA) were applied to the collected progress data herein. An outlier verification was performed, and the optimized baseline was set for each construction project type. Reflecting the fact that at this phase, KPI standardizes the project period in percentage to eliminate the factors affecting the project performance, this

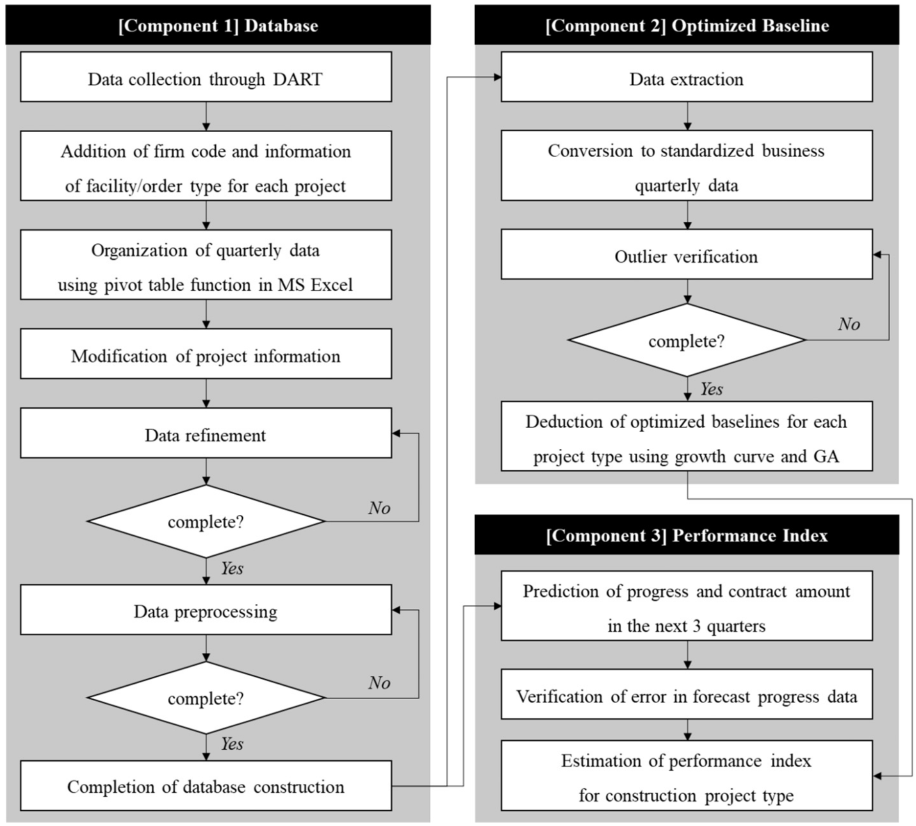


Fig. 1. EPMS development process.

study also converted the business quarter to proportion of duration.

Finally, the existing methods presented quantitative results for monitoring the construction project performance, and recent studies emphasized the need for an early detection of poor performance to ensure a successful implementation of a construction project (Haji-Kazemi and Andersen, 2013; Yoo and Kim, 2015; Kim, 2017). Therefore, a performance index was set in this study: the numerical value of the deviation of the actual data against the baseline, which was incorporated as a component of the EPMS to present the forecast results for the next three quarters based on a time series analysis.

4. Database

4.1. Overview

The progress of the projects conducted by all construction firms in Korea must be investigated to derive the ideal research results. However, obtaining these data is difficult in practice. Therefore, the data were sampled from 19 construction firms that continuously ranked in the top 30 firms nationally from 2000 to 2014 according to the annual evaluations of their construction capacity by the Ministry of Land, Infrastructure, and Transport. In addition, the data were collected from the fourth quarter of 1998 when many listed corporations began to disclose information to the third quarter of 2016 when the information disclosure was completed. Each business quarter was represented herein by a six-digit number expressed as the year followed by a number from 03 (i.e., first quarter) to 12 (i.e., fourth quarter).

4.2. Database construction procedures

First, the information commonly confirmed through DART was collected, such as the client name, project name, contract date, estimated completion date, quarterly initial contract amount, and completion amount. The data were organized using MS Excel 2016. In this phase, codes were added to the firms to identify the project subjects. The facility and order types were also set to reflect related Korean laws and standards, such as the Act on the Construction Industry and the Integrated Construction Information Classification System. The facilities were classified into the following types: (1) architectural projects consisting of residential, cultural, and educational facilities; (2) civil infrastructure projects consisting of social infrastructure like ports, roads, dams, bridges, and tunnels; (3) industrial facility projects including energy facilities, plants, and environmental facilities; and (4) other projects, such as landscaping, design reviews, and project feasibility reviews. Projects related to electricity and communications are ordered separately in Korea; hence, projects on installing pipes and Internet facilities were classified as industrial facility projects.

The orders were also classified into public and private types to consider the characteristics of the owners.

Second, the initial information was modified to include data that differed from the quarterly disclosed information of the client name, project name, contract date, and estimated completion date. In this phase, the initial contract date and the initial estimated completion date of each project were converted into quarters, and the MS Excel cells, into which the initial data were entered, were configured to identify the change in the quarterly contract amount for each project. In addition, the progress of each project was calculated based on the collected data, and two sheets were organized to confirm the quarterly progress and contract amount based on the pivot table function of MS Excel 2016.

Finally, the collected data were refined and preprocessed to ensure their validity. The data on construction suspension or "five sites besides project A" were deleted. During the preprocessing, a data mining technique was used to predict the values of missing data from the progress and contract amount sheet to improve the data reliability. Data preprocessing is a key process of data mining that enables a simple analysis because it helps secure reliable results with reduced bias caused by disrupted data and allows the direct application of general statistical methods to the supplemented missing values. Linear interpolation, which is widely used for predicting missing values, was applied to preprocessing of the progress data (Sunitha et al., 2013). The contract amount was also supplemented by replacing missing values with the nearest available data. The mathematical model for the linear interpolation applied to preprocessing of the progress data is expressed as follows:

$$f(x_k) = f(x_1) + \{(x_k - x_1)/(x_n - x_1)\} \times \{f(x_n) - f(x_1)\}, \qquad (1)$$

where $f(x_k)$ is the estimated data value of point k; $f(x_1)$ is the data of the first point actually provided; and $f(x_n)$ is the data of the nth point actually provided.

$f(x_1)$ represented the progress of the quarter immediately before point k, which is a missing value, while $f(x_n)$ was the progress in the quarter following point k. The progress of a disrupted period was estimated using the values at both ends of a quarter; hence, the distance from the first point to point k divided by the distance from the first point to point n ($x_k - x_1/x_n - x_1$) was set to 1/3.

4.3. Database construction results

Fig. 2 shows the database, which consists of two sheets used to identify the quarterly progress and the contract amount of each project.

The database was divided into four parts: (1) identification of basic information, such as the contract quarter, estimated completion quarter, client and project names, and initial contract amount [Fig. 2(a)]; (2) confirmation of detailed information, such as facility type, order type, and name of construction firm that performed each project [Fig. 2(b)]; (3) information on the quarterly progress of each project [Fig. 2(c)]; and (4) information on the quarterly contract amount of each project [Fig. 2(d)]. The two sheets had the same configuration, differing only with regard to the input data [Fig. 2(c) and (d)]. The database was constructed based on MS Excel; thus, easily searching for the project business information was possible using the filtering function. In addition, users can refer to change trends in the progress and contract amounts for projects similar to their own.

An analysis of the database configuration indicated that 15,822 projects were performed by 19 construction firms in Korea over 20 years as presented in Table 1. Architectural and private projects comprised a high proportion of the total projects at 45.37% and 53.46%, respectively. These results should reflect the recent trends in the Korean construction industry, such as the increase in orders for private-led redevelopment projects. In addition, 12,735 data elements were preprocessed, which was approximately 8% of the total 157,226 data elements for the 15,822 projects. Therefore, the effect of supplemented data on the results of this study should be negligible.

5. Optimized performance measurement baseline

5.1. Data extraction and standardization

The best practice concept was applied herein, and the data for projects with a progress of >95% in the initial estimated completion quarter were extracted. Hence, 3255 projects were extracted from the database through filtering. The project was regarded as an outlier if the progress sharply accelerated immediately before completion or the project began before the fourth quarter of 1998. Therefore, 532 projects were excluded. Table 2 presents the composition of the selected projects. A total of 2723 projects were used to derive the performance measurement baseline. A large proportion of the architectural projects were performed by the private sector because of the increase in orders for redevelopment projects mentioned earlier. As regards civil infrastructure projects, the public-sector proportion was estimated to be approximately 78%, which was believed to reflect the trend where most of these projects were ordered by the government and local autonomous entities. The public- and private-sector proportions were similar in terms of industrial facility projects because the related projects were separately ordered and implemented by the private sector in accordance with the Telecommunications Business Act.

The extracted projects (with a progress of >95% in the initial estimated completion quarter) constituted approximately 17% of the database. This result implied that a few projects in Korea met the initial completion time set in the planning phase within the 20-year period. The Korean national macro-economy strongly depends on the construction industry; hence, ways for objective monitoring and forecasting of the project performance are urgently required. We standardized the quarter in percentage units and established intervals of 0.02% by benchmarking the KPI. When the duration proportion was calculated as an odd number, that number was rounded up and moved to the closest standardized quarter.

Fig. 2. Final database: (a) basic information, (b) detailed information, (c) quarterly progress of the project, and (d) quarterly contract amount of the project.

5.2. Verification of outliers

The mean value of the progress was calculated from the duration proportion for each project type to derive an optimized model. The outliers were verified through a calculation of the standardized residuals. The data with absolute values for the standardized residuals of >3 were certainly outliers in general, while those with absolute values between 2 and 3 were very likely to be outliers (Lee and Lim, 2005).

The data with absolute values for the standardized residuals of ≥2 were removed to obtain reliable results. Table 3 presents

Table 1
Detailed database configuration.

Project type		Configuration	
		Number (EA)	Ratio (%)
Facility type	Architectural	7178	45.37
	Civil infrastructure	3929	24.83
	Industrial facility	4178	26.41
	Other projects	537	3.39
Order type	Public	7364	46.54
	Private	8458	53.46

Table 2
Composition of the projects for deriving the performance measurement baseline.

Project type	Public	Private	Total (EA)
Architectural	299	916	1215
Civil infrastructure	507	139	646
Industrial facility	325	392	717
Other projects	92	53	145
Total (EA)	1223	1500	2723

Table 3
Outlier verification results.

Project type	Number of data		
	Total number (EA)	Outlier (EA)	Data for analysis (EA)
Architectural	243	64	179
Civil infrastructure	407	70	337
Industrial facility	263	75	188
Other projects	105	30	75
Public	445	100	345
Private	246	59	187

the outlier verification results. The outlier proportions for civil infrastructure and public projects were estimated as the lowest at approximately 17% and 22%, respectively. These results were caused by the continuous entry of higher-accuracy data into DART compared to private projects because most clients were government and local autonomous entities.

5.3. Optimized model for each construction project type

The optimized performance measurement baseline was derived using the growth curve and the GA. The growth curve is a mathematical method of expressing phenomena that change over time and generally divided into linear and nonlinear models (Roush and Branton, 2005). Linear models are limited because they assume data linearity. Therefore, nonlinear models are mainly used to predict ecological, economic, and technological growth in various academic fields, including construction management (Kaufmann, 1981; Meade, 1984; Yoo and Hadipriono, 2007; Lee, 2008; Kim et al., 2010, 2013). Theoretical models were derived herein using the Gompertz curve (GC), logistic curve (LC), and reverse Gompertz curve (RGC), which are representative nonlinear growth curves, because construction projects generally have an S-shaped progress pattern. The mathematical models of these curves are given as follows:

$$\mathrm{GC}: y(t) = S \times e^{-a \times e^{-bt}}; \tag{2}$$

$$\mathrm{LC}: y(t) = \frac{S}{1 + a \times e^{-bt}} \tag{3}$$

$$\mathrm{RGC}: y(t) = S \times \left(1 - e^{-a \times e^{bt}}\right). \tag{4}$$

Here, $y(t)$ is the progress estimated using the theoretical model; t is the duration proportion (%); S is the upper asymptote of progress; e is the base of the natural logarithm; a is a shift parameter that integrates and controls the growth curve moving along the x-axis; and b is a parameter that controls the slope of each growth curve.

The parameter S was set to 1.001 under the assumption of a 1/1000 error when the maximum value of progress is reached (i.e., 100%). Parameters a and b for determining the shape of the growth curve were estimated using GA, which is a representative optimization method used in various studies on construction management to find optimal values or alternatives (Kim et al., 2010; Shin et al., 2011; Yoo et al., 2012). The results obtained with GA are known to be more accurate than those determined using traditional statistical methods, such as regression, when estimating the parameters of a growth curve (Roush and Branton, 2005). The best fitness function (BFF) was set to minimize the sum of the squared deviations between the estimated value of the theoretical model and the actual progress data and estimate the parameters herein:

$$\mathrm{BFF} = \mathrm{Min} \sum \{P(t) - f(t)\}^2, \tag{5}$$

where t is the duration proportion (%); P(t) is the actual progress value at t; and $f(t)$ is the estimated value from the theoretical model at t.

Table 4
Example of the BFF calculation.

T	$P(t)$	GC		LC		RGC	
		$f(t)$	Squared deviation	$f(t)$	Squared deviation	$f(t)$	Squared deviation
20%	28%	38%	0.0100	14%	0.0196	20%	0.0064
40%	42%	55%	0.0169	37%	0.0025	35%	0.0049
60%	69%	75%	0.0036	64%	0.0025	54%	0.0225
80%	87%	92%	0.0025	84%	0.0009	82%	0.0025
100%	100%	100%	0.0000	100%	0.0000	100%	0.0000
Sum			0.0330		0.0255		0.0363

As apparent from Table 4, the $f(t)$ values of the three growth curves were estimated and the sum of the squared deviations between P(t) and $f(t)$ was calculated when the P(t) data for five duration proportions were available.

In the above example, the curve with the smallest value was selected as the optimized baseline. Hence, the sums of the squared deviations for each curve were estimated to be 0.0330, 0.0255, and 0.0363, respectively. Therefore, LC is the model with the highest explanatory power against the actual progress. The parameters were calculated using Evolver 7.5. The initial values of the parameters were assumed to be 1, and the number of trials was set to 1000. Table 5 indicates that the best fitness values (BFVs) of the LC were calculated as being the smallest among all project types.

The adjusted R^2 was calculated to evaluate the explanation power of the actual data of the optimized model. >94% of all construction project types were derived. Fig. 3 presents the results obtained by plotting the average of the actual progress

Table 5
Parameter estimation results.

Project type	GC			LC			RGC		
	a	b	BFVs	a	b	BFVs	a	b	BFVs
Architectural	5.72	3.85	0.44	26.14	5.67	0.35	0.08	3.58	0.48
Civil infrastructure	4.75	3.91	0.71	18.95	5.59	0.62	0.08	3.80	0.84
Industrial facility	5.30	4.12	0.57	23.42	6.05	0.46	0.19	2.51	2.39
Other projects	5.86	4.33	0.25	25.13	6.19	0.19	0.26	2.14	1.40
Public	4.77	3.90	0.63	18.92	5.65	0.55	0.16	2.72	2.37
Private	5.90	3.83	0.51	28.65	5.74	0.39	0.06	4.01	0.46

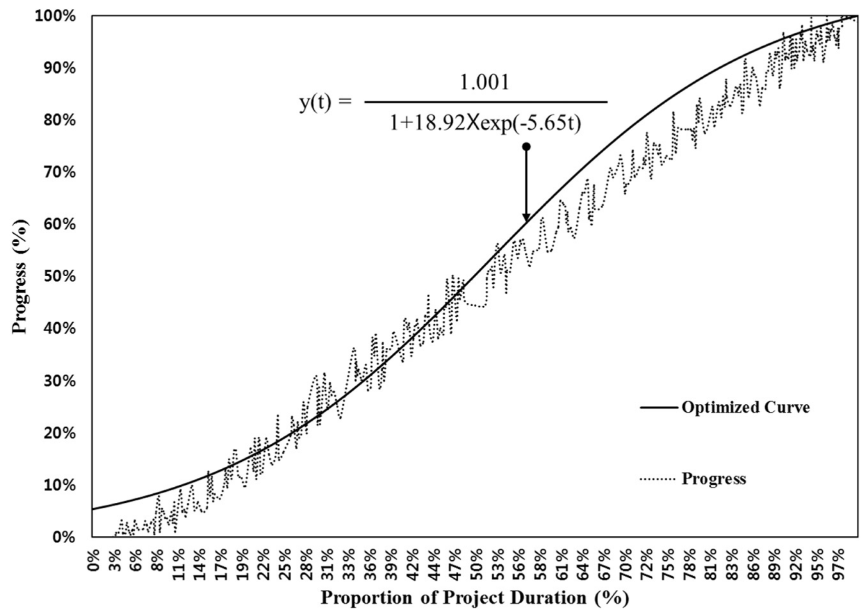


Fig. 3. Optimized theoretical model of a public project.

and standardizing the estimated value with the optimized theoretical model based on the maximum value. A public project was taken as an example.

6. Estimation of the performance index and the result analysis

6.1. Concept of the performance index

The proposed performance index (PI) converts the deviation of the progress achieved at a certain time from the performance measurement baseline of a project to a value. For example, as shown in Fig. 4, the baseline of the applied best practice was established to measure the performance of different project types [Fig. 4(a)], and the difference between the historical value collected from DART [Fig. 4(b)] and the predicted value based on the actual progress [Fig. 4(c)] was compared with the baseline [Fig. 4(d)]. In the case of Fig. 4(d), the gaps were calculated as zero if the historical and predicted values were located on the baseline, with negative and positive values being assigned below and above the baseline, respectively. For example, a negative gap can be regarded as the potential risk that may occur in the future, which has not yet been realized, but may negatively affect the project performance.

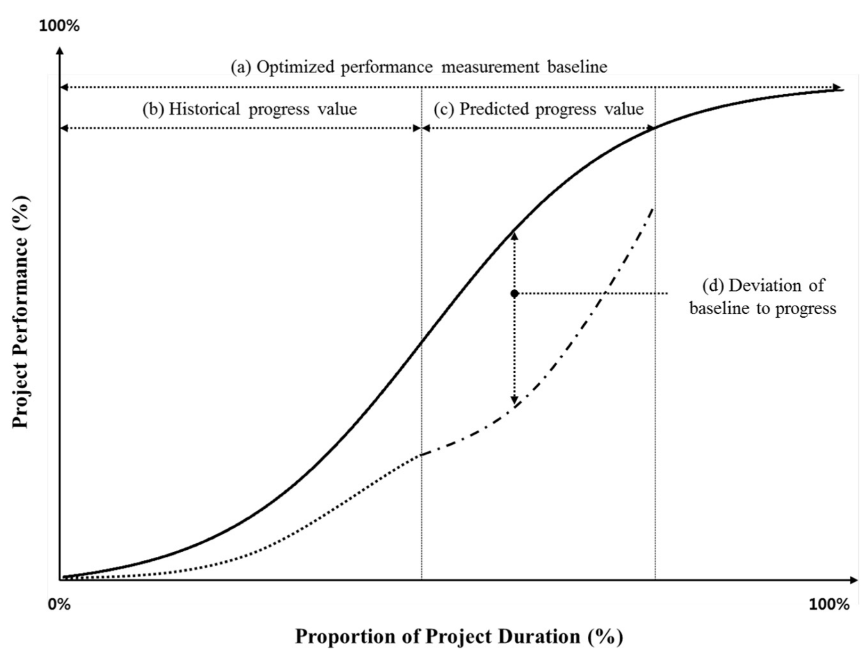


Fig. 4. PI concept: (a) optimized performance measurement baseline, (b) historical progress value, (c) predicted progress value, and (d) deviation of progress from the baseline.

The contract amount of each project was used to index the deviation of the progress from the baseline as follows:

$$PI_t = 1 - \frac{\sum Gap_t \times CA_t}{\sum SP_t \times CA_t}, \quad (6)$$

where t is the quarter of the project; PI_t is the PI in quarter t; SP_t is the performance in quarter t estimated with the baseline; Gap_t is the difference between SP_t and the progress of each project in quarter t; and CA_t is the contract amount of the project in quarter t.

If PI = 1, the project achieved the target performance or profitability according to the performance measurement baseline. In other words, PI <1 means that the project failed to reach the target performance, while PI >1 means that the target performance was exceeded.

6.2. Forecasting of progress and contract amount

An increasing interest in the objective performance measurement for early warning of potential poor performance inherent to a project has been observed in response to the recent changes in the business environment of the construction industry (Haji-Kazemi and Andersen, 2013; Yoo and Kim, 2015). The progress and the contract amount were used herein to calculate and forecast the PI. In this case, a longer forecast period increased the possibility of error occurrence (Cho, 2014). Therefore, the forecast period of the progress and the contract amount was set to the next three quarters, and the forecast of the contract amount reflected the most recent data and the data preprocessing phase. Double exponential smoothing (DES), which is a time-series analysis technique, was used to forecast the progress. Unlike the moving average method, which provides all time-series data with the same weight, DES considers the level and trend of data, thereby providing high-quality trend forecasts in the short and midterms (Kalekar, 2004; Paul and Kumar, 2011). The DES mathematical model is expressed as follows:

$$FIT_t = F_t + T_t \quad (7)$$

$$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$$

$$T_t = T_{t-1} + \gamma(F_t - F_{t-1}).$$

Here, FIT_t is the forecast value calculated using the trend-adjusted exponential smoothing method (forecast including trend); F_t is the forecast value for quarter t (calculated through simple exponential smoothing); F_{t-1} is the forecast value for quarter ($t - 1$); A_{t-1} is the actual observed value for quarter ($t - 1$); T_t is the smoothed value for quarter t; T_{t-1} is the smoothed value for quarter ($t - 1$); α is the smoothing constant ($0 \le \alpha \le 1$); and γ is the smoothing constant for the trend ($0 \le \gamma \le 1$).

The weights used for DES included α and γ, where α was usually set in the range of [0.05, 0.3]. More weight was given to the recent data as γ approached unity. α was set to 0.3, and γ was set to 1 to provide a higher weight to the recent data. The error was estimated by subtracting the forecast value for quarter t based on the data of the previous quarter ($t - 3$) from the actual progress quarter t to verify the forecast results using DES.

The approach presented herein was verified for 10 construction projects randomly extracted from the database to quantitatively evaluate the error of the progress forecast using DES. Table 6 presents the results. Hence, the absolute and mean values of the deviations were determined to be distributed in the ranges of [0.00%, 9.32%] and [1.26%, 4.99%], respectively. The estimated error was less than approximately 5% on average; hence, DES appeared to provide a relatively high accuracy when estimating the progress of future quarters.

6.3. PI estimation and analysis of the results

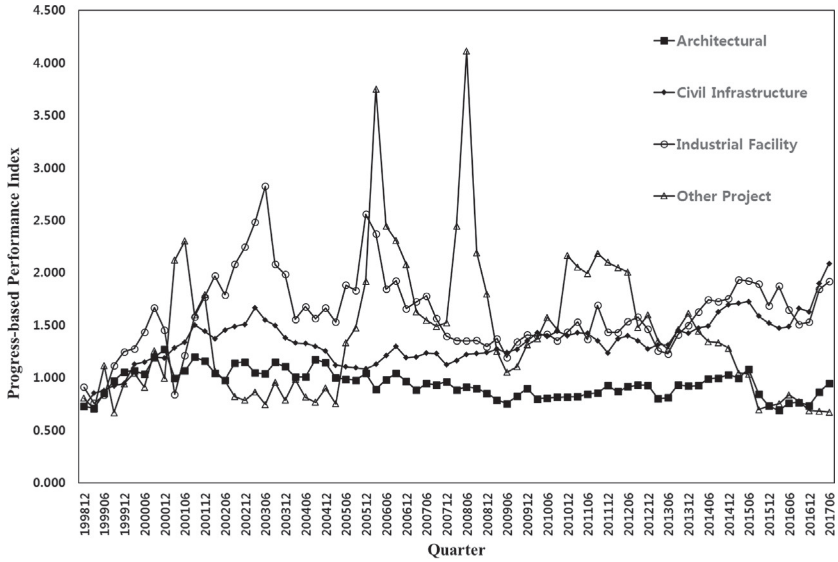
Fig. 5 shows the PI estimation results for each project type during the period from the fourth quarter of 1998 to the second quarter of 2017. The trends in the PI variation differed for each project type, and differences were observed between the maximum and minimum values and the quarterly variations of the achieved performance. We analyzed the descriptive statistics (Table 7) to quantitatively evaluate these trends. Among the facility types, the highest average value was obtained for industrial facility projects with an average of 1.61. In addition, architectural projects were the most stable, with the smallest standard deviation for the PI at 0.13. The average PI value for public projects was 1.36, which was higher than that for private projects; however, the variation of the index was relatively high.

The PI trends were analyzed by considering the construction project execution environment in Korea. The PI analysis results for each facility type are presented as follows:

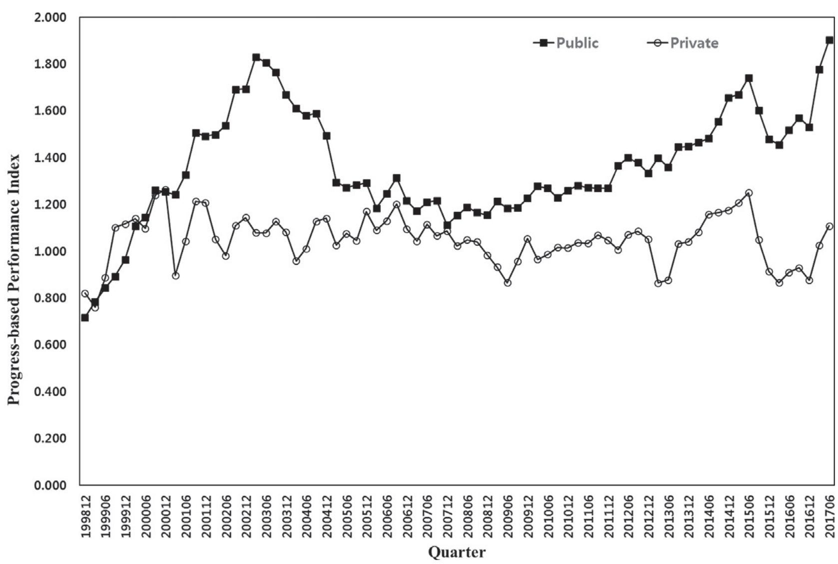
(1) The estimated PI for architectural projects had a standard deviation of 0.13; hence, the variation was stable relative to the other facility types. This result implied that Korean construction firms have a suitable performance management capability and framework for architectural projects. However, the average value was the lowest among all

Table 6
Verification of the error in the progress forecast using DES.

No.	Project type		Duration (month)	Contract amount (US $ million)	Estimation of error (%)		
	Facility	Order			Max	Min	Average
1	Architectural	Private	66	200	7.02	0.00	3.36
2	Civil	Private	30	24	6.83	0.00	3.29
3	Architectural	Public	21	3	4.11	0.00	2.28
4	Industrial	Private	33	38	7.40	0.00	4.08
5	Civil	Public	27	7	4.44	0.00	1.94
6	Architectural	Public	36	6	9.32	0.33	4.85
7	Architectural	Private	39	162	9.04	0.66	4.99
8	Civil	Public	57	10	3.00	0.00	1.26
9	Civil	Private	57	229	3.64	0.00	1.72
10	architectural	Private	39	199	5.66	0.82	3.08



(a) Facility type



(b) Order type

Fig. 5. Estimation results of the PI for each project type: by (a) facility and (b) order.

facility types at 0.95 and <1 in many quarters. In other words, the achieved performance was relatively low compared with the other facility types, which may be caused by the conditions inherent to the architectural projects in Korea, such as frequent design changes by the client and interruptions caused by climate conditions. The PI is forecast to increase after the fourth quarter of 2016, following a recent increase in orders for architectural projects. According to the statistics of the Construction Association of Korea (CAK), domestic architectural projects have been increasing since 2013. In 2016, the volume was estimated to be approximately US $111,415 million, which was approximately 77% of the total contract volume (CAK, 2016).

(2) The average and the standard deviation of the PI for civil infrastructure projects were estimated to be 1.35 and

Table 7
Descriptive statistics of the PI.

Project type	Max	Min	Average	Std. deviation
Architectural	1.27	0.69	0.95	0.13
Civil infrastructure	2.09	0.73	1.34	0.23
Industrial facility	2.83	0.76	1.61	0.37
Other projects	4.11	0.67	1.40	0.66
Public	1.90	0.72	1.36	0.24
Private	1.26	0.76	1.05	0.10

0.23, respectively. The PI was consistently above 1 from 2000, which may be because most civil infrastructure projects were public projects ordered by the Korean government, and the repetitive process and simultaneous multitasking compensated for the delays that may have occurred in the initial stages of the project. The PI is forecast to increase after the fourth quarter of 2016, which may be because large public projects ordered by the Korean government to revitalize the domestic economy after 2013 reached their peak progress at that time. The orders for public civil infrastructure projects, such as the Four Major Rivers Restoration Project, were increased to overcome the domestic economic recession in Korea caused by the Global Financial Crisis. According to the CAK, the annual order volume of civil infrastructure projects was estimated to rise from US $26,300 million in 2013 to US $33,593 million in 2016 (CAK, 2016). Therefore, the index of civil infrastructure is expected to continue to steadily grow.

(3) The PI for industrial facility projects had an average of 1.61 and a standard deviation of 0.37. These values were higher than those for the architectural and civil infrastructure projects. The high average was attributed to the excellent construction capacity of Korean construction firms with regard to the industrial facility projects. Korean construction firms are widely recognized for their ability to perform industrial facility projects and have received engineering, procurement, and construction (EPC) project orders from overseas. The higher standard deviation can be attributed to the electricity and telecommunications projects conducted over short periods. The expected declining trend in the PI after the fourth quarter of 2016 reflected the focus of Korean construction firms on overseas projects.

(4) Other projects had the highest PI average and standard deviation, which may be the result of projects reaching their peak progress being repeated and responding sensitively to the changes in the market environment. The PI is forecast to increase after the fourth quarter of 2016.

The PI analysis results with regard to order type are given below.

(1) The PI for public projects was consistently above 1 from 2000, and the average was 1.36. This was higher than the value for private projects and appeared to reflect the burden on construction firms of liquidated damages for delay. The liquidated damages for delay in Korea were estimated to be 0.1% of the contract amount per day. The standard deviation was higher than that for private projects, which may lead to a false economy caused by the Korean bidding system, which is mainly based on price, when the volume of orders is reduced in the future. Therefore, preemptive measures should be prepared for alternatives to stabilize the variation in the PI. The PI is forecast to sharply rise from the fourth quarter of 2016 because of large-scale project orders since 2013, as previously discussed for civil infrastructure projects.

(2) The standard deviation of private projects was 0.105, which was stable compared with that for public projects. This result may be attributed to the performance of each project being actively managed because the private projects were directly related to the profits of construction firms. A PI of <1 may reflect external factors, such as the recession of the Korean construction market and the change in the government real estate policy at the time. Although the PI is expected to rise after the fourth quarter of 2016, the performance of private projects is directly related to the business efficiency of construction firms, and the order trend is increasing. Therefore, efforts to achieve the planned performance remain necessary. Since 2011, the order volumes for private construction projects has steadily increased, especially in 2015 and 2016, which yielded the highest volumes at US $99,604 million and US $103,311 million, respectively (CAK, 2016).

7. Discussion

The importance of performance monitoring for achieving successful business goals is emphasized with the changes in the project execution process. A more efficient performance monitoring will be possible using existing methods, such as EVMS, if gathering credible information on the key performance indicators, such as cost, is possible. However, the existing methods are inevitably difficult to apply in a situation, where the available data for performance monitoring is limited, because of the confidentiality-based position of stakeholders on information disclosure. EPMS is expected to be used as an alternative for the standardized analysis framework for the quantitative monitoring and forecasting of project performance because it is based on credible business information. In addition, data for various performance indicators can be obtained and policies can be formulated at the government level to increase the EPMS usability if a social consensus can be established among stakeholders that performance monitoring is important.

The database developed herein was composed of project information obtained for over approximately 20 years. Therefore, stakeholders can refer to historical cases similar to their projects and utilize those cases as a basis for decision-making to set the project management direction. However, during the information gathering process, the data on the progress and the contract amount in unit projects may be missing, rendering it difficult to secure data with continuity. This situation can cause a distrust among investors, who assess the status of each firm through DART. Therefore, the listed corporations that directly input data are expected to make an effort to provide accurate project information.

Finally, the PI can support quantitative monitoring and forecasting of the performance for each project type, but cannot clearly explain the causes of variation in the index. Therefore, the EPMS must be supplemented with analyses of causes that may affect the variations in the PI and the changes in the environment faced by the project execution process. The error estimation for the forecast progress indicated that the error values for some projects were as high as approximately 9%, which was thought to be caused by the use of official data herein. This error is expected to be reduced if confidential data from within firms or organizations can be utilized.

8. Conclusion

The proposed EPMS is expected to be an effective method for quantitative monitoring of project performance because it is composed of a performance measurement baseline and an index using credible data similar to existing methods, such as EVMS. The proposed system is based on the contract amount, which is a leading indicator in the construction industry; hence, it is expected to be an effective way for the early detection of the accounting cliff phenomenon in the construction industry that could have a negative impact on individual investors as well as national macro-economy due to the huge loss at the fiscal year-end despite reporting excellent quarterly business results.

The main results of this study are summarized as follows: overall, the EPMS is built on a database that contains information about projects implemented over 20 years; hence, stakeholders can use it as a basis for efficient decision making based on similar historical cases of projects, in which they are involved in. However, in the database analysis, only 17% of the implemented projects were analyzed because they had a progress of >95% in the initial estimated completion quarter. Therefore, a more aggressive project management approach through objective performance monitoring is expected. In addition, the optimized baselines were obtained using the LC, but the results are expected to be constantly updated considering the recent increase in the importance of project management and environmental changes in the construction industry. Finally, the PI is expected to provide a numerical value for tracking and monitoring the performance of construction projects on the macroscale because it is similar to the variation of the PI and the change in the order quantity.

The proposed system is expected to be used for performance monitoring in other countries with a financial system, which may gather credible data on the quarterly progress and contract amount. In addition, this study is expected to make an academic contribution with its proposal of a standardized analysis framework that firms or organizations can use as a basis for future business planning. Future studies will involve improving the EPMS by linking it with various performance indicators, influencing factors for construction projects, such as bidding methods and business scale, and major economic indicators. Furthermore, the authors will extend the research scope to overseas construction projects and other industries and analyze methods of linking the developed framework with project management standards, such as GAPPS.

Conflict of interest

There are no conflicts of interest to declare.

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