Effect of project characteristics on project performance in construction projects based on structural equation model

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\textbf{A R T I C L E   I N F O}

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\textbf{A B S T R A C T}

Most past studies that analyze project performance and the characteristics that affect such performance consist of a simple form, in which they present the brief relationship between project performance and a few characteristics that affect it. Furthermore, due to the limitations of the research methodologies used in these studies, important characteristics were often not considered in developing the relationship between project performance and project characteristics. This study aims to analyze the overall relationship between project performance and a project’s characteristics. This study deduced (i) the overall causal relationship and (ii) the degree of influence between 17 project characteristics and five project performance indices. In order to achieve this goal, this study employed the factor analysis method and a structural equation model (SEM). In addition, this study established a SEM based on quantitative data from actual case studies as opposed to previous SEM studies that mainly use qualitative data.

The SEM developed in this study can identify the project characteristics that affect the level of project performance required by owner in the planning stage, and is thus expected to help facilitate the decision-making process in the early planning stage of a project.

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1. Introduction

The success of a construction project is the sole goal of project investors, including the owners, and contractors, and is the subject of many researches analyzing the factors that affect the success of a construction project. In addition, the owners of public projects are developing various delivery methods that consider various project characteristics affecting the success of construction projects, and are making an effort to select an appropriate contractor for each project.

In the studies that have been conducted on the delivery methods and contractor selection procedures that help make projects succeed, as well as on the successful achievement of these projects, the most frequently employed method is identifying the impact factors and developing a model for selecting an appropriate contractor or delivery method based on the relationship between project performance and the project characteristics affecting it.

In the study on the selection of the project that is appropriate for the design-build (DB) method for successful public construction projects, Molenaar and Songer (1998) analyzed the relationship between the main categories (i.e., the project, the owner, the market (design-builder), and the relationship among them) and the performance (i.e., cost, time, etc.) using regression analysis, a multivariate statistical analysis method. To achieve a successful high-rise project in Indonesia, Kaming, Olomolaiye, Holt, and Harris (1997) identified the relationship among the project characteristics (i.e., change orders, experience, and resources) through a factor analysis of the variables affecting the overrun of the project, such as time and cost. In the study conducted by Ling, Chan, Chong, and Ee (2004), regression analysis was used in predicting the performance of the DB and design-bid-build (DBB) methods, which they did to analyze the relationship between the level of project performance (i.e., cost and time) and the project characteristics affecting it.

The factor and regression analyses conducted in the abovementioned studies can establish only one relationship at a time. Even several dependent variables, as, for example, in a multivariate analysis of variance, can show only a single relationship between an independent variable and the dependent variables (Hair, Black, Babin, Anderson, & Tatham, 2006).

Not only do these analysis methods employed by the abovementioned studies fail to measure the relationships among the project characteristics; they are also fragmented in that the analyzed and deduced relationship between a few project characteristics and the project performance was based on only one project. Furthermore, the characteristics influencing the success of the project, and the appropriate model for selecting the delivery method that the aforementioned studies try to identify by analyzing the relationship between project performance and the various project characteristics, and the resulting decision-making process cannot be established.
characteristics do not consider a large number of project characteristics but focus only on a few major factors.

However, any decision is made through multi-level approaches, with several alternatives, since any decision-making process can become very complex depending on the progress of time and the changes in the circumstances. In addition, the limited level of awareness of decision-makers makes it difficult to solve complex issues in a real situation, so that only the solution appropriate for the circumstances at hand is sought (Simon, 1976; Lindblom, 1978). In other words, the relationship between a few project characteristics and project performance, which is expressed in an arithmetic equation, may exhibit low adaptability in terms of the decision-making process, and thus have less possibility of being considered in terms of the aspects of the performance required by the owner and the ever-changing project characteristics. Therefore, this study examines how various project characteristics affect project performance (i.e., construction duration, construction cost, etc.), using a structural equation model (SEM).

2. Structural equation model

SEM is a multivariate analysis method that was developed to examine causal relationships in the social sciences, which use mainly qualitative analysis. Similar to multiple-regression equations, SEM analyzes the structure of the interrelationship expressed as a series of arithmetic equations.

According to Hair et al. (2006), compared with other types of multivariate-data analysis methods, SEM has three distinct characteristics, which are as follows:

(i) it has the ability to estimate multiple and interrelated dependence relationships;
(ii) it has the ability to represent unobserved concepts in these relationships and to correct measurement errors in the estimation process; and
(iii) it has the ability to define a model explaining the entire set of relationships.

Due to these advantages of SEM, more and more studies are being conducted in the engineering fields that make use of it (Molenaar, Washington, & Diekmann, 2000; Wong & Cheung, 2005; Dulaimi, Nepal, & Park, 2005; Islam & Faniran, 2005).

SEM consists of measurement and structural components (Byrne, 1994). As shown in Fig. 1, the measurement component is a characterized model that measures exogenous variables (illustrated by numbers (1–4) in Fig. 1) with observed variables (illustrated by “X1–X17” in Fig. 1). The structural component is a characterized model of the causal relationship between the exogenous and endogenous variables (illustrated by “Y1–Y5” in Fig. 1).

Observed variables have data that a researcher can directly measure (i.e., numeric responses to a rating scale item) while latent variables are variables that are of interest to a researcher but are not directly observable (Islam & Faniran, 2005).

In general, the overall structure of SEM can be simply expressed in the following Eqs. (1)–(3).

\[ \eta = B\eta + \Gamma \xi + \zeta \]  

where, \( \eta \) is a vector for endogenous variables, \( \xi \) is a vector for exogenous variables. \( B \) and \( \Gamma \) are coefficient matrices, and \( \zeta \) is a vector that expresses latent errors in the equations. \( \eta \) and \( \xi \) are, in fact, variables that are not measured and expressed in Eqs. (2) and (3), respectively, by the measured variables \( y \) (observed indicators of \( \eta \)) and \( x \) (observed indicators of \( \xi \)).

\[ y = A\eta + e \] 

\[ x = A\zeta + \delta \] 

where, \( A \) is the coefficient vector relating \( y \) to \( \eta \) or \( x \) to \( \zeta \), and \( e \) and \( \delta \) are error terms associated with the observed \( x \) or \( y \) variables. These equations are multivariate regression equations associated with variables that are easily observed, and with latent variables that are not observed (Bollen, 1989; Hair et al., 2006). \( \beta \) and \( \Gamma \) in Eq. (1) represent the coefficient matrix for \( \eta \) and that for \( \xi \), respectively. Also, \( A \) in Eq. (2) is the coefficient rating \( y \) to \( \eta \) (i.e., \( A \) in Eq. (4)), whereas \( A \) in Eq. (3) is the coefficient rating \( x \) to \( \xi \) (i.e., \( A \) in Eq. (4)). Therefore, \( \beta \) is a matrix consisting of \( A_{y} \) and \( \Gamma \) is a matrix consisting of \( A_{x} \), which can be expressed in the following equation:

\[ z = [\gamma \quad o \quad \delta] \] 

where \( Z \) = observed polytomous vector; \( A_y = \) coefficient rating \( y \) to \( \eta \); and \( A_x = \) coefficient rating \( x \) to \( \xi \).

SEM differs from other types of multivariate analysis models not in terms of how it analyzes variance but in terms of the covariance analysis method it uses. Consequently, SEM deals with the covariance among the measured variables or observed sample covariance matrices. Although the use of a covariance matrix or a correlation matrix among the variants measured with SEM is not always clear, SEM programs can use one of these two matrices as their input (Hair et al., 2006).

SEM is usually developed in three stages. The first stage is to define the structural and measurement components (measured variables, latent variables, etc.). The second stage is to set up a hypothetical model. The third stage is to assess the validity of the structural model. SEM is a developmental process of determining a hypothetical model based on the structural and measurement components defined in the first stage, of validating the appropriateness of the hypothetical model, and of showing the optimal causal relationship. Generally, a SEM is verified by evaluating its appropriateness. Various Goodness of Fit (GOF) measures are used to evaluate the appropriateness of SEM. This is explained in detail in the section with heading “Step 4” of this paper.

3. Research methodology

The main objective of this study is to identify the causal relationship between project performance and a project’s characteristics by executing a quantitative data analysis on several real construction projects. As shown in Fig. 2, this study consists of a total of five steps.

Firstly, an intensive literature review was conducted to identify the project performance indices used in this study and the various project characteristics that affect such indices and that are often used to measure the possibility of the success of a construction project. The various project characteristics and project performance indices that were used in this study were selected through this intensive literature review, and their definitions were also presented. Secondly, cases were collected on which SEM could be applied, and a quantitative evaluation was performed. The collected cases were multi-family housing and road construction projects completed between 2000 and 2005. Out of 165 cases, 151 were selected and evaluated (14 cases were not selected as they deviated from the confidence interval). Thirdly, a factor analysis of the project characteristics (or observed variables) affecting the project performance was performed to deduce the exogenous variables that comprised the SEM model. Four exogenous variables were deduced from such factor analysis. In addition to the exogenous variables, the hypothetical model was developed based on the various project characteristics and performance indices that were selected in the first step. Fourthly, the developed hypothetical model was continuously revised so that it could best explain the causal
Fig. 1. Exogenous, observed, and endogenous variables in the SEM.

Fig. 2. Research framework.
relationship between project performance and various project characteristics. After developing the revised model, various GOF measures were made, and the level of appropriateness of the model was verified. As a result, a SEM was developed that can explain the causal relationship between various project characteristics and project performance indices, and the degrees of influence of such characteristics on project performance. Finally, using the developed SEM, the relationship between the project characteristics and project performance was explained, and the causal relationship between them was examined.

3.1. Step 1: development of project performance indices and characteristics

The project characteristics and performance indices identified through the intensive literature review constituted the observed variables and the endogenous variables, respectively, of the SEM. The term “factor,” which refers to the attributes that affected the project performance in the previous studies, represents the various characteristics of the project, such as its external characteristics, the participants' characteristics, and the environmental characteristics. Therefore, all these characteristics and factors were referred to as “characteristics” in this paper.

3.1.1. Characteristics affecting project performance

Many researchers have defined various characteristics affecting project performance. The study conducted by Ling et al. (2004) presented the project characteristics affecting project performances, which were divided into three categories: (i) project characteristics, (ii) owner and consultant characteristics, and (iii) the contractor characteristics. The project characteristics include the gross floor area of the project, the form of contract, the type of building, the level of design and construction complexity, the percentage of repetitive elements, the time given to contractors to prepare their bids, the number of bidders, the bid evaluation and selection criteria, etc. The level of construction sophistication of the contractors and their experience with similar projects, among others, were considered owner and consultant characteristics. In the case of the contractor characteristics, communication among the project team members, the contractor's paid-up capital and staffing level, etc. were considered (Ling et al., 2004). Alhazmi and McCaffer (2000) presented the type of project, the time constraints, the degree of flexibility and complexity, the payment method, and the integration of the design and construction as project characteristics affecting project performance. The project characteristics that overrun the construction duration and cost were divided into six categories (weather, cost data, resource shortages, experience, design changes, and labor productivity) in the study conducted by Kaming et al. (1997).

The various characteristics that affect project performance, based on the analysis of previous research, can generally be categorized into the characteristics of the project, the project participants, and the market. Among the various characteristics that were used in the previous research, those that were used in this paper were selected based on the following two criteria: (1) the characteristics that were often used in the previous research; and (2) data regarding the characteristics can be collected for the case studies. As it is difficult to collect data on weather and labor productivity from the 165 case studies that were conducted in this study, these characteristics were not included.

As shown in Table 1, the following ten project environment characteristics were selected: (i) project scale, (ii) time to budget fixed, (iii) type of project, (iv) level of construction complexity, (v) percentage of repetitive elements, (vi) project scope definition completion when bids are invited, (vii) flexibility of the work scope, (viii) level of design preparation by owner, (ix) location of site, and (x) time given to contractors to prepare their bids. The seven project participant characteristics were selected as follows: (i) owner's capability for construction management, (ii) owner's administrative burden, (iii) owner's experience with similar projects, (iv) owner's level of control over the design changes, (v) communication among project team members, (vi) contractor's paid-up capital, and (vii) contractor's capability for construction management.

Meanwhile, the 17 aforementioned project characteristics were measured using the method defined in the third column of Table 1. In other words, each project was evaluated based on the nominal and ordinal scales, from one to five. For example, if the project environment characteristic "X1 (project scale)" had a project cost of $1 million to $3 million, it was given 1 point on the ordinal scale; if $3 million to $5 million, 2 points; if $5 million to $10 million, 3 points; if $10 million to $20 million, 4 points; and if over $20 million, 5 points. In addition, the project environment characteristic "X4 (level of construction complexity)" was given a rating based on the ordinal scale consisting of one (very complex) to five (not complex) points.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Characteristics affecting project performance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Characteristics</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Project environment characteristics</td>
</tr>
<tr>
<td>X1</td>
<td>Project scale</td>
</tr>
<tr>
<td>X2</td>
<td>Time to budget fixed</td>
</tr>
<tr>
<td>X3</td>
<td>Type of project</td>
</tr>
<tr>
<td>X4</td>
<td>Level of construction complexity</td>
</tr>
<tr>
<td>X5</td>
<td>Percent of repetitive elements</td>
</tr>
<tr>
<td>X6</td>
<td>Project scope definition completion when bids are invited</td>
</tr>
</tbody>
</table>
3.1.2. Project performance indices

Compared to the various project characteristics that affect the project performances as pointed out in previous studies, the project performance indices are mostly similar. The project performance indices presented in these studies are generally divided into quantitative and qualitative indices. The quantitative performance indices measured construction cost (i.e., award rate, unit cost, cost growth, etc.) and construction time (i.e., construction speed, delivery speed, schedule growth, etc.), while the qualitative performance indices evaluated the quality (i.e., turnover quality, system quality, etc.), and the owner’s satisfaction (Konchar & Sanvido, 1998; Molenaar & Songer, 1998; Alhazmi & McCaffer, 2000; Ling et al., 2004).

As shown in Table 2, only the project performance indices that could be evaluated quantitatively were considered in this study. Since construction cost and time were used as the most representative performance indices, they were also selected as project performance indices for this study. According to the method defined in the third column of Table 2, this study evaluated the award rate, unit cost, and cost growth as the project performance indices on cost, and the schedule growth and construction speed as the project performance indices on time.

3.2. Step 2: data collection

For the input data for the establishment of a SEM, data were collected from 165 multi-family housing and road construction projects completed between 2000 and 2005. To obtain more accurate information on the performances of these case projects, 32 case projects were collected from the public agency A, which specializes in road construction, and 34 road construction projects were collected from public agencies B and C, which are affiliated with the Ministry of Construction and Transportation and which have similar organizational systems and tasks. Moreover, in the case of the multi-family housing project, 99 case projects were collected from public agencies D and E, which specialize in the procurement of public housing construction projects and have similar organizational systems and tasks.

Using the collected cases, the various project characteristics and performances were evaluated using the method defined in the third column of Tables 1 and 2, and the input data set was completed. The descriptive statistics of the data collected from the 165 cases were then analyzed to increase the significance of the data. As a result, the study excluded 14 cases (5 road and 9 multi-family housing projects) that exceeded the 5% significance level. Finally, as shown in Table 3, data from 151 cases (61 road and 90 multi-family housing projects) were collected.

The percentages of repetitive elements (X5: refer to Table 1), a project characteristic, were found to be mostly identical since the collected cases were multi-family housing and road projects. Therefore, it is insignificant to evaluate “X5” based on ordinal scales of one to five. This means that it is difficult to deduce the covariance among the variables used in establishing the SEM, for which reason it was excluded.

3.3. Step 3-1: definition of constructs

Based on the data set collected from the 151 cases, the observed variables, exogenous variables, and endogenous variables comprising the SEM were described as follows:

(i) observed variables: characteristics that affected the project performances;
(ii) exogenous variables: latent variables that were deduced from a factor analysis, that represent the observed variables, and that are associated with endogenous variables; and
(iii) endogenous variables: the project performance indices.

The observed variables and endogenous variables could have been obtained by analyzing the data from the 151 cases as shown in Tables 1 and 2. However since the exogenous variables were latent variables, there had to be a plan for obtaining the exogenous variables.

Generally, two methods are used to obtain exogenous variables. In the first method, exogenous variables are presented based on the results (theories) of previous studies. In another method, latent variables are identified using factor analysis (Hair et al., 2006). Since no previous studies have pointed out exogenous variables that affect the observed and endogenous variables, this study deduces exogenous variables via factor analysis.

3.3.1. Factor analysis for exogenous variables

The factor analysis method used in this study to deduce exogenous variables was also used to verify the underlying variables or factors with which the pattern of correlations among various observed variables could be explained. The general purpose of the factor analysis was to find a method of simplifying the information from the many initial variables into smaller new variables. In other words, the factor analysis that was conducted minimized the loss of the existing variables and discovered the estimated fundamental constructs that underlay the variables (Hair et al., 2006). Therefore, this study deduced the exogenous variables that represent the characteristics (measured variables) affecting project performance by conducting factor analysis.

Factor analysis was performed using SPSS 12.0 (for Windows). The factors were rotated using varimax rotation to maximize the variance of the squared loadings for each factor and to produce clear factor loadings. A scree plot was used to determine the number of factors to be considered (Koksal & Arditi, 2004). As shown in Fig. 3, the four components were extracted by specifying the minimum initial eigenvalue of one. These four components (i.e., project characteristics, owner characteristics, contractor characteristics, and environment characteristics) are the displayed explanation power (% of the variance explained) of 84.645% as shown in Table 4. Each component had 37.472, 24.939, 13.799, and 8.435% of the variance explained. Therefore, this study defined four components as exogenous variables.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Project performance indices.</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Performance indices</td>
</tr>
<tr>
<td>Cost</td>
<td>Y1 Award rate (%)</td>
</tr>
<tr>
<td>Y2 Unit cost (dollars/m²)</td>
<td>Final project cost/area</td>
</tr>
<tr>
<td>Y3 Cost growth (%)</td>
<td>([Final project cost–contract cost]/contract cost) × 100</td>
</tr>
<tr>
<td>Time</td>
<td>Y4 Schedule growth (%)</td>
</tr>
<tr>
<td>Y5 Construction speed (m²/day)</td>
<td>Area/(as built construction end date–as built construction start date)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Number of analyzed cases.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of project</td>
<td>Road construction project</td>
</tr>
<tr>
<td>Organization</td>
<td>A</td>
</tr>
<tr>
<td>No. of first cases collected</td>
<td>32</td>
</tr>
<tr>
<td>No. of exclude cases</td>
<td>5</td>
</tr>
<tr>
<td>No. of cases finally analyzed</td>
<td>61</td>
</tr>
</tbody>
</table>
3.4. STEP 3-2: Development of a hypothetical model

The hypothesis of this study is that various project characteristics affect the project performance. Eq. (5) shows the hypothetical model defined in this study based on the hypothesis.

\[
PPI = \beta_1 \gamma_1 \omega_1 \chi_1 CAPP_1 + \beta_2 \gamma_2 \omega_2 \chi_2 CAPP_2 + \ldots + \beta_n \gamma_n \omega_n \chi_n CAPP_n + \xi_1
\]

where \( PPI \) = Project Performance Index, \( CAPP_i \) = \( i \)th Characteristics Affecting Project Performance, \( \gamma_i \) = \( i \)th project characteristics, \( \omega_i \) = \( i \)th owner characteristics, \( \chi_i \) = \( i \)th contractor characteristics, and \( \xi \) = latent error.

This study used Chronbach alpha values to determine the appropriateness of the developed hypothetical model and the accuracy of the results of the factor analysis (Peter, 1979; Sharma, 1996; Wong & Cheung, 2005). Generally, if a Chronbach alpha value is over 0.7, the collected data are considered to have significant consistency; and if it is over 0.6, it is believed to be apt for consideration (Sharma, 1996). Table 5 shows the three factors (project characteristics, contractor characteristics, and owner characteristics) with high alpha values of 0.915, 0.914 and 0.989, respectively, due to which they were considered to have excellent internal consistency. However, the alpha value of the environment characteristics was rather low. Although this low alpha value could pose a problem, the study included the environmental characteristics in the establishment of the hypothetical model, as it was an important characteristic in the projects.

3.5. Step 4: model development and validation

3.5.1. Model modification and validation

As mentioned in Section 2, the SEM was established based on the covariance matrices between two variables. A common method of calculating the covariance in a SEM is the maximum likelihood method (MLM) (Hair et al., 2006). In this study, the AMOS 7.0 software was used to calculate the formation of the causal relationship among the concepts that comprise the hypothetical model, and to analyze the level of influence among the causal relationships. As described above, this study confirmed the SEM by verifying its appropriateness from the results of the covariance structural analysis. Various GOF measures were used for this purpose. Generally, the ratio for \( \chi^2/df \) (degree of freedom), the goodness-of-fit index (GFI), the comparative index (CFI), the root mean square error of approximation (RMSEA), and the normal-fit index (NFI) have been used to verify the appropriateness of SEM (Molenar et al., 2000; Wong & Cheung, 2005; Islam & Faniran, 2005).

Table 6 shows the covariance structural analysis that was performed based on the hypothetical model. It shows that the ratios for \( \chi^2/df \): 8.243, GFI: 0.627, CFI: 0.708, RMSEA: 0.220, and NFI: 0.683 exhibited low appropriateness, making it impossible for them to be selected as models. Therefore, the hypothetical model was revised to come up with a model that has an excellent level of appropriateness.

Table 4

<table>
<thead>
<tr>
<th>No.</th>
<th>Characteristics affecting project performance (observed variables)</th>
<th>Factor Loading</th>
<th>Percent of variance explained</th>
<th>Cumulative percent of variance explained</th>
<th>Components (exogenous variables)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X10</td>
<td>Time given to contractors to prepare their bids</td>
<td>.973</td>
<td>37.472</td>
<td>37.472</td>
<td>Project characteristics</td>
</tr>
<tr>
<td>X8</td>
<td>Level of design preparation by owner</td>
<td>.918</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X6</td>
<td>Project scope definition completion when bid is invited</td>
<td>.896</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X2</td>
<td>Time to budget fixed</td>
<td>.881</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X12</td>
<td>Owner’s administrative burden</td>
<td>.877</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X7</td>
<td>Flexibility of the work scope</td>
<td>.824</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X4</td>
<td>Level of construction complexity</td>
<td>.893</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X17</td>
<td>Contractor’s capability for construction management</td>
<td>.956</td>
<td>24.939</td>
<td>62.411</td>
<td>Contractor characteristics</td>
</tr>
<tr>
<td>X16</td>
<td>Contractor’s paid-up capital</td>
<td>.947</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X15</td>
<td>Communication among project team member</td>
<td>.856</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X1</td>
<td>Project scale</td>
<td>.585</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X11</td>
<td>Owner’s capability for construction management</td>
<td>.986</td>
<td>13.799</td>
<td>76.210</td>
<td>Owner characteristics</td>
</tr>
<tr>
<td>X14</td>
<td>Owner’s level of control over the design changes</td>
<td>.980</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X13</td>
<td>Owner’s experience with similar projects</td>
<td>.975</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X9</td>
<td>Location of site</td>
<td>.815</td>
<td>8.435</td>
<td>84.645</td>
<td>Environment characteristics</td>
</tr>
<tr>
<td>X3</td>
<td>Type of project</td>
<td>.812</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As discussed in Table 4, the exogenous variables are defined as "project characteristics," "owner characteristics," "contractor characteristics," and "environment characteristics." For instance, the "project characteristics" consists of seven measured variables:

(i) time given to the contractors to prepare their bids (X10, factor loading = 0.973),
(ii) level of design preparation of the owner (X8, factor loading = 0.918),
(iii) project scope definition completion when bid is invited (X6, factor loading = 0.896),
(iv) time to budget fixed (X2, factor loading = 0.881),
(v) owner’s administrative burden (X12, factor loading = 0.877),
(vi) flexibility of the work scope (X7, factor loading = 0.824), and
(vii) level of construction complexity (X4, factor loading = 0.893).
Two methods could have been used to revise the model. The first method involved deleting the path that showed a low causal relationship, and the second method involved an additional causal relationship (Sarker, Aulakh, & Cavusgil, 1998; Wong & Cheung, 2005). In this study, the second method was used. By establishing an additional causal relationship to the hypothetical model, this study compared the level of appropriateness of the improved model to the hypothetical model. This study also used the modification index, one of the outputs of AMOS, which is the most widely used method of refining the SEM model (Molenaar et al., 2000; Wong & Cheung, 2005; Islam & Faniran, 2005).

Based on the modification index offered by AMOS 7.0, the hypothetical model was revised a few times. The final model that was developed is shown in Table 6. Table 6 shows that the model’s level of appropriateness improved significantly with the ratios for $\chi^2/df$: 2.394, GFI: 0.831, CFI: 0.951, RMSEA: 0.096, and NFI: 0.920. For detailed information on the GOF measures, please refer to Hair et al. (2006) due to editorial constraints.

### Table 5
<table>
<thead>
<tr>
<th>Reliability test of hypothetical model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exogenous variables (observed variables)</td>
</tr>
<tr>
<td>Chronbach’s alpha value</td>
</tr>
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</table>

### Table 6
<table>
<thead>
<tr>
<th>Goodness of fit measures for SEM.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GOF measure</td>
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<td>$\chi^2/df$</td>
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<td>GFI</td>
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<td>RMSEA</td>
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<td>NFI</td>
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### 3.5.2. Model specification

As shown in Fig. 4, the final SEM was deduced from the development of a model with an excellent level of appropriateness through revisions of the hypothetical model.

The final model consisted of 16 observed variables that affected the project performances of “X1–X17,” excluding “X5,” four exogenous variables deduced from the factor analysis, and five endogenous variables that represented the project performance index. Fig. 4 shows that the final model also consisted of the structural components, which were exogenous and endogenous variables, and the four measurement components, which were exogenous and observed variables. Furthermore, the group of variables (observed, exogenous, and endogenous variables) explains well the causal relationship between various project characteristics and their performances. Moreover, described on each arrow (refer to Fig. 4) is a coefficient that shows the level of influence in each causal relationship. Generally, a coefficient is calculated using MLE, based on the covariance matrix, and this value is similar to the regression weights in regression analysis, which is widely used to explain the level of influence (Bollen, 1989; Hair et al., 2006). However, the error value (e1–e17) of each observed variable is not shown in Fig. 4 so that the relationship between various project characteristics and performances can be clearly defined. In addition, this study used dotted lines to show the causal relationship that exhibited a low level of confidence, and did not show the coefficient value. Tables 7–10 show the statistical amounts of the measurement and structural components, including the measurement errors and confidence levels. The detailed information regarding Tables 7–10 are presented in Section 3.6 of this paper.

![Fig. 4. Final SEM between CIPP and PPI.](image-url)
3.6. Step 5: discussion of results

3.6.1. Relationship between project characteristics and project performance (Table 7)

As shown in Table 7, the project characteristics with respect to the structural components negatively influenced “award rate” (standardized coefficient = -0.583, p < 0.001), positively influenced “cost growth” (standardized coefficient = 0.347, p < 0.001), and negatively influenced “construction speed” (standardized coefficient = -0.222, p < 0.01). Moreover, the project characteristics with respect to the measurement components positively influenced the following observed variables: (i) the time given to contractors to prepare bid (X10, standardized coefficient = 0.985, p < 0.001), (ii) the level of design preparation by owner (X8, standardized coefficient = 0.936), (iii) the project scope definition completion when bids are invited (X6, standardized coefficient = 0.920, p < 0.001), (iv) the time to budget fixed (X2, standardized coefficient = 0.910, p < 0.001), (v) the owner’s administrative burden (X12, standardized coefficient = 0.855, p < 0.001), and (vi) the flexibility of work scope (X7, standardized coefficient = 0.796, p < 0.001). However, the “level of construction complexity (X4, standardized coefficient = 0.055, p > 0.01)” was
shown to have been associated not with the project characteristics but with the “location characteristics,” one of the other exogenous variables.

When the various project characteristics affecting the project performances and the methods of measuring these are considered, as defined in Tables 1 and 2, the above results can be interpreted as follows. The higher the “level of design preparation by owner,” the “project scope definition completion when bids are invited,” and the “flexibility of work scope,” (the observed variables that comprised the project characteristics) are, the lower the “award rate,” the slower the “construction speed,” and the higher the “cost growth.” Furthermore, the more delayed the “time to budget fixed,” the higher the “owner’s administration burden,” and the shorter the “time given to contractors to prepare bid,” the lower the “award rate” and the “construction speed,” and the higher the “cost growth.” The result that the higher the “level of design preparation by the owner (X8)” and the “project scope definition completion when bids are invited(X6)” is, the worse the cost and time performance become is different from the widely accepted idea. Such result can be found in the following relationships: (1) the larger the “project scale (X1)” is, the higher the degree of the “level of design preparation by the owner (X8)” is; and (2) the larger the “project scale (X1)” is, the higher the “cost growth (Y3)” and “schedule growth (Y4)” become. Large-scale projects, such as those that involve road construction, have not only a high “level of design preparation by the owner” but also a high “cost growth” and “schedule growth.” Consequently, a large scale road construction project with high uncertainty would be worse in terms of cost and time performances, despite the high “level of design preparation by the owner” and “project scope definition completion when bids are invited.”

3.6.2. Relationship between contractor characteristics and project performance (Table 8)

As shown in Table 8, the contractor characteristics with respect to the structural components positively influenced the “unit cost” (standardized coefficient = 0.226, p < 0.05), “cost growth” (standardized coefficient = 0.284, p < 0.05), and “schedule growth” (standardized coefficient = 0.139). Moreover, in the measurement component, the contractor characteristics positively influenced the “contractor’s capability for construction management (X17, standardized coefficient = 0.990, p < 0.001),” the “contractor’s paid-up capital (X16, standardized coefficient = 0.981, p < 0.01),” “communication among project team members (X15, standardized coefficient = 0.901, p < 0.01),” and the “project scale (X1, standardized coefficient = 0.101).” In other words, the larger the “project scale” is, the higher the “contractor’s capability for construction management” and the “contractor’s paid-up capital” are, and the more active “communication among project team members” is, the larger the “unit cost” and the higher the “cost growth” and “schedule growth.” Such results may have been due to the addition of a new relationship in the process of developing the final model.

The result that the better the “communication among the project team members(X15)” was, the higher the “cost growth (Y3)” and “schedule growth (Y4)” became is different from the widely accepted idea. Such result can be found in the following relationships: (1) the higher the grade of the “contractor’s paid-up capital (X16)” is, the more the “type of project (X3)” becomes concentrated on a road construction project; and (2) the larger the “project scale(X1)” is, the higher the “cost growth (Y3)” and “schedule growth(Y4)” become. Meanwhile, contractors with a high paid-up capital generally have good management skills, as well as good communication among their team members. Therefore, if they would concentrate on large scale road construction projects, the project performance in terms of cost and schedule growth could become worse even though there is good communication among the members of their team.

3.6.3. Relationship between owner characteristics and project performance (Table 9)

As shown in Table 9, in the structural component, the owner characteristics negatively influenced the “schedule growth (standardized coefficient = −0.307, p < 0.001),” and positively influenced the “construction speed (standardized coefficient = 0.388, p < 0.001).” In the measurement component, the owner characteristics influenced the “owner’s capability for construction management (X11, standardized coefficient = 0.998, p < 0.001),” the “owner’s level of control over the design changes (X14, standardized coefficient = 0.990, p < 0.001),” and the “owner’s experience in similar projects (X13, standardized coefficient = 0.958),”

In other words, the higher the “owner’s capability for construction management” and the “owner’s level of control over the design changes” are, and the more the “owner’s experience in similar projects” is, the shorter the “schedule growth” and the faster the “construction speed.”

3.6.4. Relationship between environment characteristics and project performance (Table 10)

As shown in Table 10, in the structural component, the environment characteristics positively influenced the “unit cost (standardized coefficient = 0.216),” and negatively influenced the “construction speed (standardized coefficient = −0.500, p < 0.001)" and the “schedule growth (standardized coefficient = −0.435, p < 0.001).” In the measurement component, the environment characteristics positively influenced the “location of the site (X9, standardized coefficient = 0.267)” and the “type of project (X3, standardized coefficient = 1.733, p < 0.001),” and negatively influenced the “level of construction complexity (X4, standardized coefficient = −0.869, p < 0.001).” In addition, as described above, the “level of construction complexity” was first considered to have been related to the project characteristics in the hypothetical model (refer to Fig. 1), but was later seen to have had a more significant relationship with the environment characteristics (refer to Fig. 4).

The abovementioned results show that the simpler the “level of construction complexity” is, the better the “location of site (i.e., the level of approach on site)” is, and the closer the “type of project” to the multi-family housing construction is, the higher the “unit cost,” the lower the “schedule growth,” and the slower the “construction speed.” The result that the lower the “schedule growth (Y4)" was, the slower the “construction speed (Y5)" become can be interpreted by the following relationships: (1) the closer the “type of project (X3)" is to the multiple housing project, the lower the “schedule growth (Y4)" and the slower the “construction speed (Y5)" become. As such, a multi-family housing project generally has a low uncertainty of the construction schedule estimation and also a relatively lower construction speed compared to a road construction project because of their characteristic such as repetitiveness and complexity. Therefore, in multi-family housing projects, despite the lower schedule growth, the construction speed is expected to be slow. Meanwhile, because the multi-family housing project in the downtown area (i.e., the closer the “location of site(X9)" is to the downtown area) has many obstacles, such as heavy traffic, in terms of construction speed, the construction speed may become slow.

3.6.5. Other relationships between the variables

In the process of developing the final SEM, a number of new and significant relationships were identified. As shown in Fig. 4, the “unit cost,” an endogenous variable, was shown to affect the “schedule growth” positively (standardized coefficient = 0.254, p < 0.001). This means that the larger the “unit cost” of a project is, the higher the “schedule growth” becomes. Another relationship shown in
Fig. 4 is that the “project size (X1)” positively affects (standardized coefficient = .113, p < 0.001) the “design preparation by the owner (X8)”, while the “contractor's paid-up capital (X16)” negatively affects the “type of project (X3)” (standardized coefficient = −.408, p < 0.001). The larger a project is, the better the design prepared by the owner is, in order to reduce the risks. The higher the “contractors’ paid-up capital” is, the more the contractor focuses on road construction projects, which are larger in scale than other public projects.

4. Conclusion

Many previous studies on project performance and the project characteristics that affect it have shown the relationship between a few project characteristics and project performance as a single arithmetic equation to help overcome the methodological limitations of regression and factor analyses and to improve their statistical accuracy. However, the relationship between a few project characteristics and project performance, as expressed in an arithmetic equation, may not be highly applicable if considered in terms of the dynamic decision-making process, and has only a slight possibility of being considered comprehensively in terms of the performance required by the owner and the various ever-changing characteristics. Therefore, this study analyzed the overall relationship between project performance and a project’s characteristics, and the level of influence of the latter on the former. In other words, this study deduced the overall causal relationship and level of influence among 17 project characteristics categorized as project characteristics, owner characteristics, contractor characteristics, and environment characteristics, and the five categories of project performance, including construction cost and time.

To analyze such causal relationship and levels of influence, this study used factor analysis and structural-equation modeling (SEM). In addition, as opposed to previous SEM studies that used qualitative data analysis, this study developed SEM based on quantitative data from actual case studies.

The SEM developed in this study shows that the project characteristics, which consisted of six detailed characteristics, positively influenced the “cost growth (coefficient = 0.347)” and negatively influenced the “award rate (coefficient = −0.583)” and “construction speed (coefficient = −0.222).” Also, the contractor characteristics, which consisted of four detailed characteristics, positively influenced the “unit cost (coefficient = 0.226),” the “cost growth (coefficient = 0.284),” and the “schedule growth (coefficient = 0.139),” whereas the owner characteristics, which consisted of three detailed characteristics, negatively influenced the “schedule growth (coefficient = −0.307)” and positively influenced the “construction speed (coefficient = 0.388).” Finally, the environmental characteristics, which consisted of three detailed characteristics, positively influenced the “unit cost (coefficient = 0.216)” and negatively influenced the “schedule growth (coefficient = −0.500)” and the “construction speed (coefficient = −0.435).”

The SEM that resulted from this study can point out the project characteristics that affect the level of project performance demanded by the owner in the planning stage for the successful execution of the project. Thus, it is expected to help facilitate the decision-making process in the initial project planning stage. However, the SEM presented in this study is not part of a direct plan to make a project successful. Rather, this study introduced the project characteristics that should be considered for the successful execution of a project. Despite the high appropriateness of the final SEM, however, the consideration of the environmental characteristics (chronbach alpha value: 0.577) in the final SEM can be regarded as a limitation of this study.

If the methodology used in this study is combined with delivery methods after determining the performance and characteristics of various types of projects, such as office buildings, it is believed that a method or standard for selecting an efficient delivery method can be developed.

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