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Structural Equation Model for Construction Equipment Selection and Contractor Competitive Advantages

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Abstract

The selection and use of appropriate construction equipment contributes to operational efficiency and contractor competitive advantages. However, numerous factors are involved in the selection of suitable construction equipment. A review of the existing literature revealed a lack of research on the causal relationships between construction equipment selection factors and contractor competitive advantages. Therefore, this study attempted to identify the selection factors through a survey of contractors' opinions on the levels of importance of the factors that are relevant to construction equipment selection and competitive advantages. The survey data were analyzed using Structural Equation Modeling (SEM). The results suggest the following six major selection factors and their respective weights of relative importance: compatibility with site characteristics (25%), services and maintenance (19%), costs (15%), safety and environmental effects (14%), ease of acquisition (14%), and technology and innovation (13%). These selection factors influence contractor competitive advantages in terms of financial stability, corporate image and reputation, bidding opportunity, and technical capacity, and their weights of relative importance are 31%, 25%, 22%, and 22%, respectively. The findings of this study shed light on the causal relationships between the selection of appropriate construction equipment and contractor competitive advantages.

Keywords: *construction equipment, selection, contractor, competitive advantage, Structural Equation Modeling (SEM)*

1. Introduction

Most large construction projects require various types of construction equipment to perform tasks. In addition to enhancing operational efficiency, the use of construction equipment helps to achieve project targets and contractors' goals. Depending on the complexity, the completion of a construction project can be realized with either a simple set or a full array of construction equipment and machinery. Thus, the rational selection of appropriate construction equipment ensures that the entire project meets the planned schedule, budget and quality. In addition, a possible causal relationship exists between the selection of appropriate equipment and the contractor's competitive advantages. Previous studies have investigated the selection of construction equipment and contractor competitive advantages. Hassan (2010) proposed the following 10 procedural steps to select indoor material handling equipment for manufacturing and logistics facilities: specify and prioritize requirements, set and decompose objectives, establish performance measures, decompose functions, determine candidate equipment classes, design subsystems, select equipment type from a class, determine the number of required units of an equipment type, determine the specifications of the selected equipment, and evaluate the design. Samee and Pongpeng (2012) suggested a procedure for helping contractor firms to select the most appropriate equipment type. The procedure begins with preparations for either a construction project bid or for current binding contracts; then, a construction method is selected for the planned project; the equipment needs in terms of type, capacity and quantity appropriate for the project are analyzed; one type of equipment is selected for consideration; a cost-benefit analysis of the three equipment procurement modes is performed, i.e., buying, renting and leasing; the best procurement mode for the equipment is selected; selection factors for all types of equipment and for all procurement modes are developed; all equipment is evaluated; a meeting is called to evaluate the results; the best equipment is selected; all types of required equipment are obtained; and finally, all types of the selected equipment are recorded.

Day (1991) reported that the selection of equipment is dependent on several constraints imposed by the job and by the contractual obligations. Specifically, these constraints were construction operation, job specification requirements, conditions of the job site, location of the job site, time allowed to complete the job,

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balance of interdependent equipment, mobility required of the equipment, and equipment versatility. Blundon (1980) proposed numerous factors that influence the selection of construction equipment. These factors included equipment costs; equipment maintainability; availability of work-market analysis; availability of equipment and replacement parts; contractor's needs-specific requirements for current or future projects; mobility, versatility and adaptability; transportability, assembly, dismantling time, and logistics; fuel consumption–energy policy; compatibility with existing fleet to balance interdependent equipment; influence of climatic conditions, site conditions and time scheduled for the project; expected economic life and obsolescence; equipment durability and reliability; required operator skills and training programs; company bidding strategy–equipment costs; backup dealer service and reputation; equipment brand name loyalty; equipment power and capacity; availability of trained service personnel; availability of proper support equipment and tools; safety and environmental protection standards; available equipment options; salvage value of new equipment; and operator convenience.

Harris (1989) proposed the following important selection criteria for earth-moving equipment: function to be performed, machine capacity, method of operation, limitations of the method, cost of the method, cost comparison with other methods, and possible modifications to the design of the project under consideration. Alkass *et al.* (2003) developed a computer model using queuing theory to select earth-moving equipment, e.g., loaders and haulers. Their proposed model was tested on four criteria: equipment capacity; equipment availability; cost, productivity and safety of the equipment; and equipment dimensions. Alkass and Harries (1988) proposed an expert system for road construction. This system relied on eight criteria to base a decision on how to select earth-moving equipment: type of work, material swell factor, weather conditions, equipment conditions, maneuvering, operator efficiency, delays, and excavation configuration. In one study by Gate and Scarpa (1980), the authors considered the following four groups of factors in selecting earth-moving equipment of the appropriate type and size: spatial relationships, soil characteristics, contract provisions, and logistical considerations.

In the selection of construction cranes, Shapira and Goldenberg (2007) considered the following factors: company policy toward owning versus renting, site ground conditions, company project forecast, commercial considerations, procurement method and subcontracting, company project specialization, administration of day rentals, dependence on outsourcing, shifting responsibility to an external party, night work shifts, progress plan and timetable, interaction with other equipment, tradition, previous experience, pieces of equipment to manage, coverage of staging areas by cranes, site congestion, obstacles on site, labor availability, noise levels, site accessibility, heavy traffic, owner/client satisfaction, poor visibility due to weather conditions, strong winds, equipment age and reliability, overlapping of crane work envelopes, and obstruction of crane operator view. Dalalah *et al.* (2010) introduced several types of cranes, e.g., mobile cranes, tower cranes and derrick cranes, and factors that influence their selection: building height; project duration; power supply; load lifting frequency; operator visibility; costs associated with move in, setup, and move out; cost of renting; productivity; initial planning and engineering; safety; soil stability and ground conditions; access road requirements and site accessibility; and operating clearance. Shapira and Schexnayder (1999) investigated the selection of mobile cranes for buildings and proposed the following selection factors: lifting assignments, structure height, hook coverage, maneuverability, surface conditions, project schedule, double handling, preparatory works, ownership, availability for renting, operator, safety, transportability, weather, and environment.

Alkass *et al.* (1993) developed a computer model to aid in the selection of equipment for concrete transportation and placement. This model included the following factors for evaluating concrete transportation equipment: vehicle capacity, vehicle output, site characteristics, weather conditions, operator efficiency, rental costs, and temporary haul roads. For the selection of concrete placing equipment, the authors suggested accounting for the following factors: site characteristics, equipment availability, continuity of operation, effect of permanent work, weather conditions, temporary works, time restrictions, and concrete specifications. Burt *et al.* (2005) proposed a model for the selection of mining equipment, i.e., trucks. The factors incorporated into the selection model included the material characteristics of the mine, loading equipment, haul route requirements, maneuvering space, dumping conditions, capacity, engine power and altitude limitations, final drive gear ratios for mechanical drives, choice of two-axle or three-axle configuration, choice of mechanical or electrical drive system, and tire size, tread and ply rating. Chan *et al.* (2001) developed an expert system using four main selection factors, i.e., performance measures, technical aspects, economic aspects, and strategic aspects, to select material handling equipment (e.g., conveyors, overhead conveyors cranes, industrial trucks, automated guided vehicles, robots or storage/retrieval systems).

To gauge contractors' competitiveness, Tan *et al.* (2007) investigated Hong Kong's construction industry and presented a list of key indicators of competitiveness: corporate image, technical ability, financial ability, marketing ability, management skills, and human resource strength. Hoang (2010) developed a competitiveness assessment model based on data from Canadian and Vietnamese construction companies using the Analytic Hierarchy Process (AHP) technique and the Multi-Attribute Utility Theory (MAUT). The assessment model encompassed four groups of factors: organization performance (human and knowledge, finance and profit, other organization resources, bids, competitive strategy, and organization structure); project performance (time, cost, quality, and other project management issues); environment and client (organization environmental awareness, organization social and industry conditions, client and supplier environment, client satisfaction, and relationship); and innovation and development (strategy to develop, research and development ability, human resource development and learning, technological ability, flexibility, and marketing). Orozco *et al.* (2011) conducted a survey of top managers of Chilean general contractors and identified the following competitiveness factors: financial indexes (profit margin, cash flow/liquidity, and productivity of investments); client satisfaction (satisfaction with service, delivery time, and satisfaction with product); society satisfaction (respect for laws and regulations and environmental consciousness); bidding effectiveness (contract volume growth and percentage of contracts won); future abilities (cost reduction abilities and cutting-edge technology applied to projects); personnel satisfaction (personnel motivation, career prospect and employee development, and organizational atmosphere); and traditional project performance indexes (cost, quality, time, and health and safety). Han *et al.* (2014) developed a competitiveness model for evaluating the global construction industry based on the data from 22 countries. This evaluation model comprised 2 factors: attractiveness of the construction industry (construction market breadth, construction market growth rate, market stability, and construction risk) and competitiveness of the construction business (construction competitiveness, design competitiveness, and cost competitiveness).

A review of the literature revealed that the existing research works either attempted to identify the selection factors applicable to specific types of construction equipment or examined the contractor competitiveness factors. There have been no research studies on the causal relationships between the selection of construction equipment and contractor competitive advantages. The knowledge of such relationships would provide a better understanding of the selection factors that contribute to contractor competitive advantages. Thus, the aim of this study was to identify those contributing factors at both the project and company levels through their causal relationships (i.e., the influence of the equipment selection on contractor competitive advantages).

2. Conceptual Framework

In this study, the relationships between construction equipment selection and contractor competitive advantages were modeled using Structural Equation Modeling (SEM). SEM is a multivariate analysis technique in which the relationships between manifested or observed variables (i.e., directly measured on a five-point Likert scale) and latent or unobserved variables (i.e., not directly measured but rather measured in terms of observed variables) are determined. Two models are used for SEM: measurement and structural models. The measurement model shows the latent variables and their corresponding observed variables, whereas the structural model describes the relationships between the latent variables. Fig. 1 illustrates the principal structural equation model used in this study to determine the relationships between construction equipment selection and contractor competitive advantages.

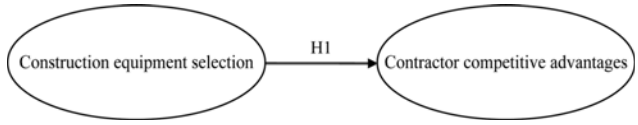

Fig. 1. Principal Structural Equation Model of the Relationships

As shown in Fig. 1, the structural model consists of two primary latent variables: "construction equipment selection" and "contractor competitive advantages". The latent variables are in the ellipses, and the directions of their conceptual influence are indicated by arrows. The basic proposition of the model is that "construction equipment selection" directly influences "contractor competitive advantages". Thus, the relationships between the two latent variables can be hypothesized as follows:

H1: "Construction equipment selection" directly influences "contractor competitive advantages".

Based on the literature review presented in the Introduction, the two primary latent variables can be described by sub-structural equation models (i.e., the measurement models), as shown in Figs. 2 and 3.

Figure 2 depicts eight latent variables that constitute "construction equipment selection": functions and capability, operations and user relations, ease of acquisition, services and maintenance, technology and innovation, safety and environmental effects, compatibility with site characteristics, and cost. Each latent variable is measured (shown by the arrow directions) by its corresponding observed variables (shown in boxes). For example, the functions and capability latent variable contains six observed variables: dimensions and weight, power, type of fuel, type of work performed, rapidity and movement, and ease of re/installation and displacement. In this figure, the double-headed arrows represent correlations between two latent variables. Fig. 3 illustrates the sub-structural equation model of the primary latent variable for "contractor competitive advantages," in which there are four latent variables: financial stability, technical capacity, bidding opportunity, and corporate image and reputation. Similarly, the latent variables of competitive advantages contain their corresponding observed variables.

To determine which latent variables of the "construction equipment selection" (Fig. 2) influence the "contractor competitive advantages" (Fig. 3), H1 is divided into the following sub-hypotheses:

H1.1: functions and capacity of equipment directly influences "contractor competitive advantages".

H1.2: operations and user relations of equipment directly influences "contractor competitive advantages".

H1.3: ease of acquisition of equipment directly influences "contractor competitive advantages".

H1.4: services and maintenance of equipment directly influences "contractor competitive advantages".

H1.5: technology and innovation of equipment directly influences "contractor competitive advantages".

H1.6: safety and environmental effects of equipment directly influences "contractor competitive advantages".

H1.7: compatibility with site characteristics of equipment directly influences "contractor competitive advantages".

H1.8: cost of equipment directly influences "contractor competitive advantages".

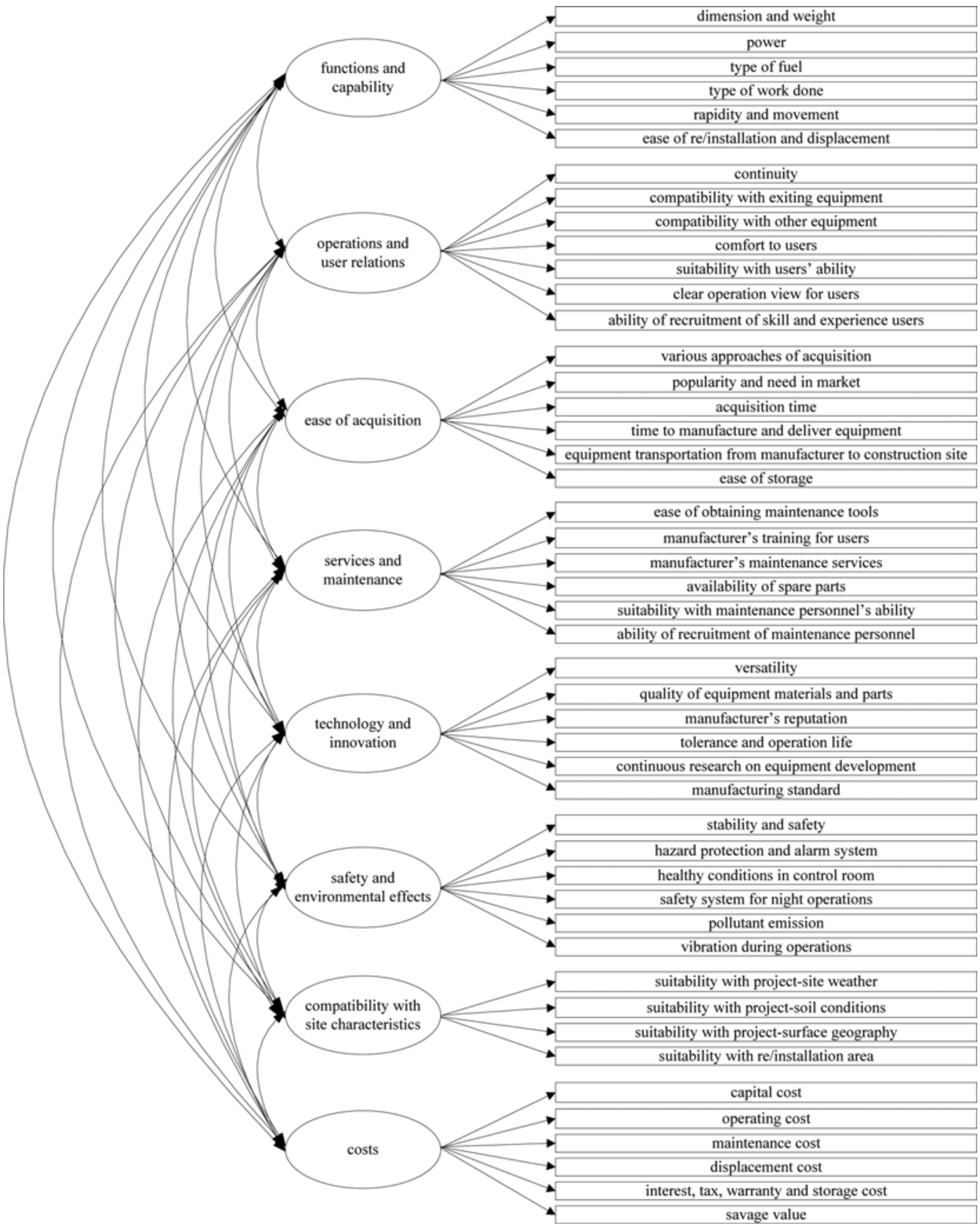

Fig. 2. Sub-structural Equation model for “Construction Equipment Selection”

3. Methodology

3.1 Content Analysis for Existing Equipment Selection and Competitive Advantage Factors

After the previous studies on the factors for construction equipment selection and contractor competitive advantages have been reviewed, a content analysis method was employed to categorize all these factors into groups as follows:

- The factors (suggested by the previous studies) for construction equipment selection can be inductively categorized into 8 groups: functions and capability, operations and user relations, ease of acquisition, services and maintenance, technology and innovation, safety and environmental effects, compatibility with site characteristics, and cost.
- The factors (suggested by the previous studies) for contractor competitive advantages can be inductively categorized into 4 groups: financial stability, technical capacity, bidding opportunity, and corporate image and reputation.

The interpretation of this categorization was performed by connecting these groups with their affiliated factors as shown in

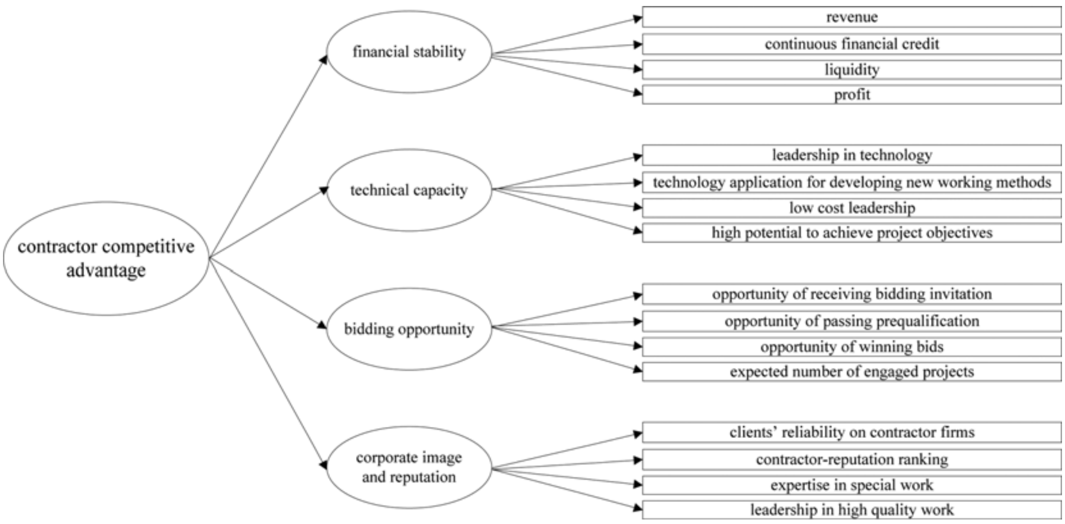

Fig. 3. Sub-structural Equation Model for "Contractor Competitive Advantages"

Figs. 2-3.

3.2 Data Collection

For the collection of data, a quantitative method was used via an opinion cross-sectional survey of Thai contractors with experience in both civil engineering and building works. The survey respondents were owners of contractor firms, project managers, project engineers, senior engineers, and site engineers. The participants were asked to identify the levels of importance of the construction equipment selection factors (referred to as variables in the SEM analysis) and contractor competitive advantage factors. In addition, they were asked about their views regarding the levels of influence that "construction equipment selection" has on "contractor competitive advantages".

A five-point Likert scale questionnaire was constructed as shown in Appendices 1-3, where 1 indicated an extremely low level of importance and 5 indicated an extremely high level of importance. A total of 800 copies of the questionnaire were distributed online to contractors located in Thailand's capital of Bangkok. Of the total, 442 questionnaires were received, representing a response rate of 55%. According to Babbie (1989), any return rate over 50% can be reported. Of the responded questionnaires, 51% of the respondents were engaged in civil engineering works, and the remaining 49% of the respondents were engaged in building works. In addition, 54% of the respondents had an average annual construction volume of less than US$17 million, with 17% between US$17-US$34 million and 29% greater than US$34 million (Baht was exchanged to US dollars using a rate of 30 Bahts/Dollar).

The questionnaire was also tested to confirm its reliability and validity. Cronbach's alpha was used to test the *internal consistency* reliability of the scale. The value of alpha ranges from 0 to 1, where the higher the alpha value is, the more reliable the scale is. An alpha value of greater than 0.7 indicates good reliability (SPSS, 1998). In this study, the factors pertaining to "construction equipment selection" and those relevant to "contractor competitive advantages" had alpha values of 0.93 and 0.91, respectively. Moreover, the Spearman rank correlation was used to test the validity of all observed variables belonging to "construction equipment selection" and "contractor competitive advantages". According to Nunnally (1967), if all observed variables can collectively explain the latent variables, they should be correlated with one another. Pongpeng and Liston (2003) used the correlation between variables for validation. In this study, it was found that all of the observed variables for the latent variables were correlated, thereby confirming the validity of the questionnaire.

3.3 Data Analysis

Based on the conceptual framework (Figs. 1-3), the Amos (version 20) software program was used to develop and analyze the structural equation models. The structural equation model contains two models: a measurement model and a structural model. The measurement model shows how latent variables are measured by observed variables, and the structural model presents the relationships between latent variables. The analysis of the structural equation model (i.e., the SEM analysis) was then performed by analyzing both models. The steps of the SEM analysis are as follows:

- Examine the measurement model for "construction equipment selection" (Fig. 2)
- Examine the measurement model for "contractor competitive advantages" (Fig. 3); and
- Examine the structural equation model to explore the causal relationships between "construction equipment selection" and "contractor competitive advantages" (H1.1-H1.8).

The SEM analysis tests the goodness-of-fit between the conceptual structural equation models and the sampled data to determine the relationships (i.e., structural parameters, e.g., regression weight, correlation, and R^2 values) between observed variables and observed variables, between observed variables and latent variables, and between latent variables and latent variables.

4. Results

The mean score for the question of whether "construction equipment selection" influences "contractor competitive advantages" was 4.32 (out of 5), which is considered extremely high. Hence, it is possible to conclude that "construction equipment selection" plays a role in "contractor competitive advantages", thereby confirming the validity of the structural equation model in Fig. 1. In the following, the SEM analysis results are divided into the overall fit of structural equation models and structural parameters.

4.1 Overall Fit of Structural Equation Models

During the SEM analysis, the conceptual structural equation models (Figs. 2-3) were modified (i.e., some variables were removed to improve the goodness-of-fit.) until satisfactory structural models were identified based on the criterion values shown in Table 1. The final structural models along with their structural parameters are presented in Figs. 4-6. The final measurement models for "construction equipment selection" and "contractor competitive advantages" are depicted in Figs. 4 and 5, respectively, and Fig. 6 presents the final structural equation model. Table 1 compares the goodness-of-fit criteria and goodness-of-fit indices for all of the structural equation models.

Table 1 shows that the index values of all of the structural

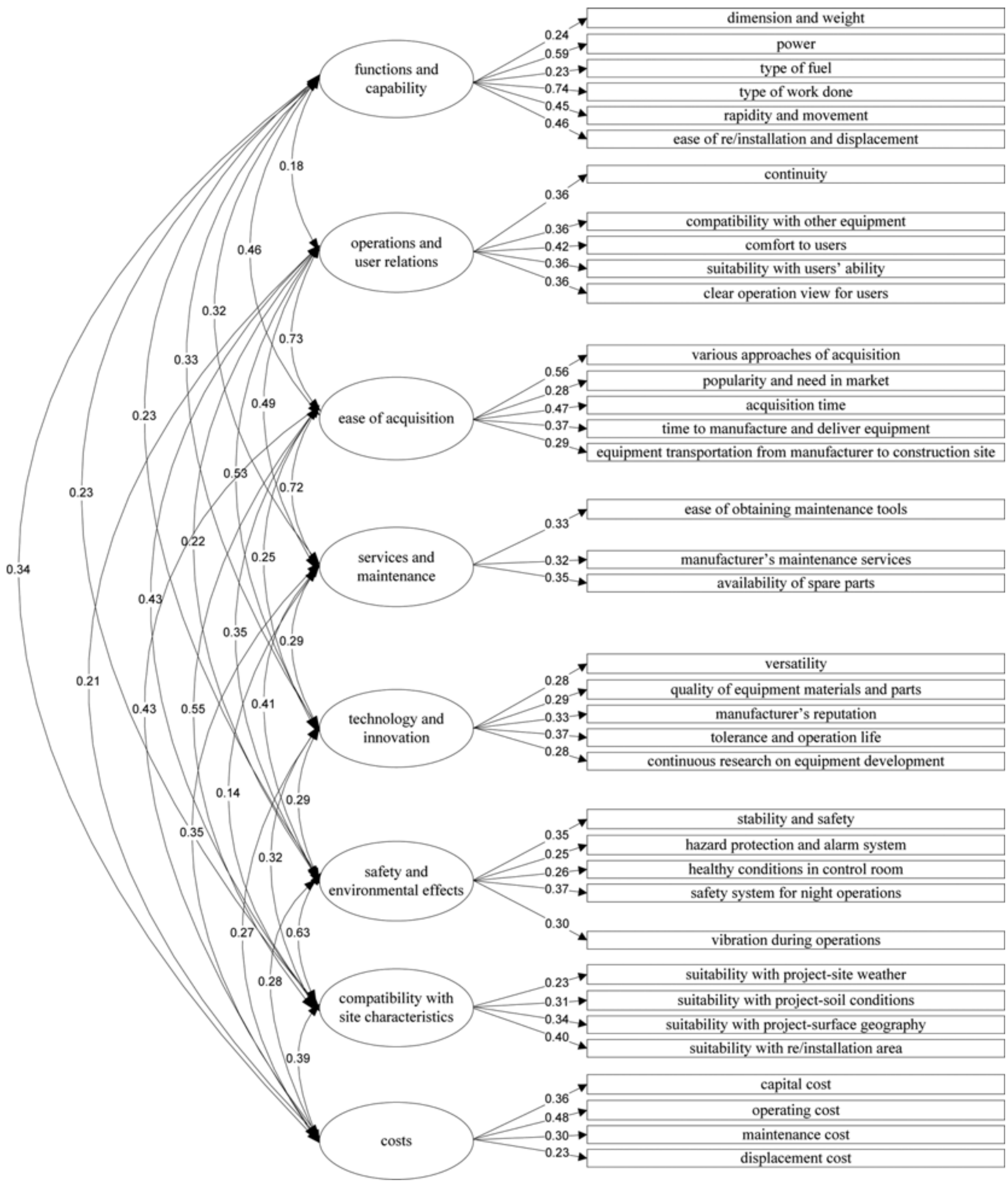

Fig. 4. Final Measurement Model Pertaining to "Construction Equipment Selection"

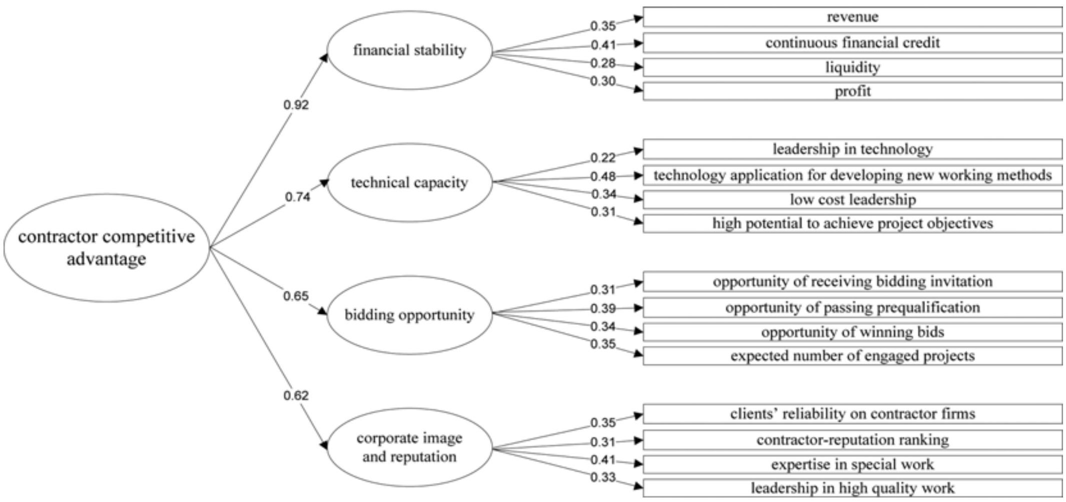

Fig. 5. Final Measurement Model for "Contractor Competitive Advantages"

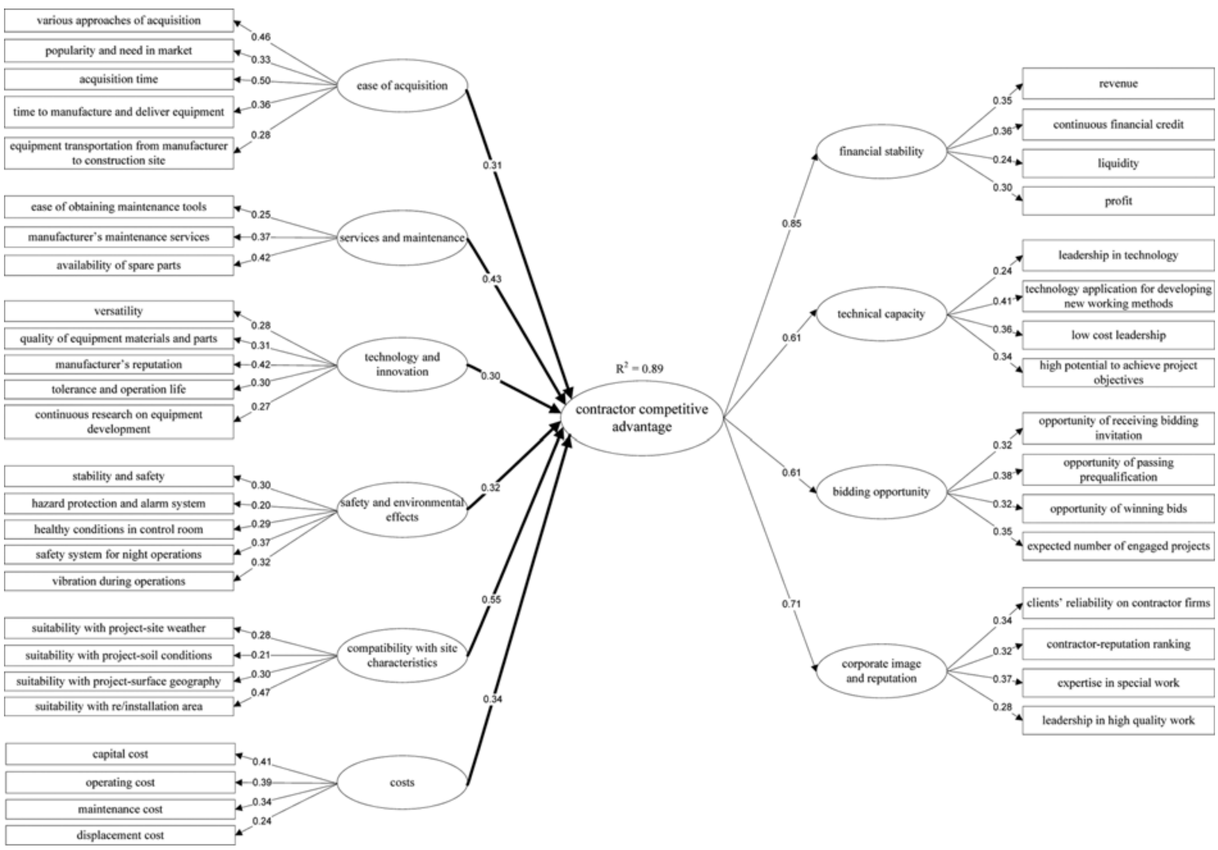

Fig. 6. Final Structural Equation Model Depicting the Influences of "Construction Equipment Selection" on "Contractor Competitive Advantages"

models satisfy all of the criterion values, indicating that all of the structural models fit the sampled data. Fig. 4 shows eight latent variables of the measurement model pertaining to "construction equipment selection" and their corresponding observed variables: (1) functions and capability (dimensions and weight, power, type of fuel, type of work done, rapidity and movement, and ease of re/installation); (2) operations and user relations (continuity, compatibility with other equipment, user comfort, suitability with users' ability, and clear operation view for users); (3) ease of acquisition (various approaches of acquisition, popularity and need in market, acquisition time, time to manufacture and deliver equipment, and equipment transportation from manufacturer to construction site); (4) services and maintenance (ease of obtaining maintenance tools, manufacturer's maintenance services, and availability of spare parts); (5) technology and innovation (versatility, quality of equipment materials and parts, manufacturer's

Table 1. Comparison of Goodness-of-fit Criteria and Goodness-of-fit Indices for all the Structural Equation Models

No	Criteria	Criterion value indicating goodness-of-fit between model and sampled data	Index values indicating goodness-of-fit of		
			Model for "construction equipment selection"	Model for "contractor competitive advantages"	Structural model
1	*p* value: probability of obtaining as large of a discrepancy that was obtained with the present sample. (Arbuckle, 2011)	$0.05 < p \leq 1.00$ (Hair *et al*., 2010)	0.455	0.664	0.397
2	χ^2/df (relative chi-square): minimum discrepancy divided by its degrees of freedom. (Arbuckle, 2011)	$0 < \chi^2/df \leq 2$ (Hair *et al*., 2010; Ullman, 2001)	1.005	0.935	1.012
3	GFI (goodness of fit index): measures the relative amount of the variances and covariances in the empirical covariance matrix that is predicted by the model-implied covariance matrix. (Schermelleh-Engel1 *et al*., 2003)	0.90 ≤ GFI ≤ 1.00 (Hair *et al*., 2010)	0.936	0.975	0.923
4	AGFI (adjusted goodness of fit index): adjusts the GFI by adjusting for the bias resulting from model complexity. (Schermelleh-Engel1 *et al.,* 2003; Hair *et al*., 2010)	0.90 ≤ AGFI ≤ 1.00 (Schumacker and Lomax, 2010)	0.922	0.966	0.911
5	IFI (incremental fit index): also known as comparative or relative fit index, which does not use the chi-square in its raw form but compares the chi-square value to a baseline model. (Hooper *et al*., 2008)	0.90 ≤ IFI ≤ 1.00 (Hair *et al*., 2010)	0.997	1.000	0.988
6	CFI (comparative fit index): one of the fit indices less affected by sample size and avoids the underestimation of fit often noted in small samples. (Schermelleh-Engel *et al*., 2003; Hair *et al.,* 2010)	0.90 ≤ CFI ≤ 1.00 (Hair *et al*., 2010)	0.997	1.000	0.986
7	RMR (root mean square residual): square root of the average squared amount by which the sample variances and covariances differ from their estimates obtained under the assumption that the model is correct. (Arbuckle, 2011)	0 ≤ RMR ≤ 0.05 (Diamantopoulos and Siguaw, 2000)	0.018	0.017	0.023
8	RMSEA (root mean square error of approximation): a measure of approximate fit in the population and is therefore concerned with the discrepancy due to approximation. (Schermelleh-Engel1*et al*., 2003)	0 ≤ RMSEA ≤ 0.08 (Hair *et al*., 2010; Schumacker and Lomax, 2010)	0.004	0.000	0.005
9	TLI (Tucker-Lewis coefficient): an incremental fit, which is actually a comparison of the normalized chi-square values for the null and specified model that takes the model complexity into account to some degree (Hair *et al*., 2010)	0.90 ≤ TLI ≤ 1.00 (Schumacker and Lomax, 2010)	0.996	1.000	0.985

reputation, tolerance and operation life, and continuous research on equipment development); (6) safety and environmental effects (stability and safety, hazard protection and alarm systems, healthy conditions in control room, safety system for night operations, and vibrations during operations); (7) compatibility with site characteristics (suitability with project-site weather, suitability with project-soil conditions, suitability with project-surface geography, and suitability with re/installation area); and (8) costs (capital cost, operating cost, maintenance cost, and displacement cost).

Figure 5 shows the measurement model for "contractor competitive advantages", which consists of four latent variables and their corresponding observed variables: (1) financial stability (revenue, continuous financial credit, liquidity, and profit); (2) technical capacity (leadership in technology, technology application for developing new working methods, low-cost leadership, and high potential to achieve project objectives); (3) bid opportunity (opportunity to receive bid invitations, opportunity to pass prequalification, opportunity to win bids, and expected number of engaged projects); and (4) corporate image and reputation (clients' reliability on contractor firms, contractor-reputation ranking, expertise in special work, and leadership in high-quality work).

Figure 6 shows the overall final structural equation model with the structural parameters. The bold arrows indicate the influence that the latent variables (pertaining to "construction equipment selection") have on "contractor competitive advantages". In this figure, "contractor competitive advantages" are influenced by six latent variables: ease of acquisition, services and maintenance, technology and innovation, safety and environmental effects, compatibility with site characteristics, and cost. However, *functions and capability* and *operations and user relations* have no significant influence on "contractor competitive advantages". This overall structural model has an R^2 value of 0.89, which means that 89% of the variance of the "contractor competitive advantages" can be explained by the six latent variables.

4.2 Structural Parameters

Table 2 presents the structural parameters for the overall final structural model. In this table, if the p-value < 0.05, the alternative

Table 2. Structural Parameters and Hypothesis Test

Hypo-the-sis	Latent variables describing "construction equipment selection"	Measurement model for "contractor competitive advantages"	Standardized regression weight	p-value	Test of hypothesis	Squared multiple correlation, R^2
H1.1	functions and capability	contractor competitive advantages	0.10	0.213	Reject	0.89
H1.2	operations and user relations	contractor competitive advantages	0.17	0.114	Reject	
H1.3	ease of acquisition	contractor competitive advantages	0.31	0.012	Accept	
H1.4	services and maintenance	contractor competitive advantages	0.43	0.044	Accept	
H1.5	technology and innovation	contractor competitive advantages	0.30	0.044	Accept	
H1.6	safety and environmental effects	contractor competitive advantages	0.32	0.048	Accept	
H1.7	compatibility with site characteristics	contractor competitive advantages	0.55	0.014	Accept	
H1.8	cost	contractor competitive advantages	0.34	0.028	Accept	

hypothesis is accepted. Because the p-values of H1.1-H1.2 were greater than 0.05, they were rejected, which indicates that the sampled data did not support both hypotheses. However, the p-values of H1.3-H1.8 were less than 0.05, indicating that H1.3-H1.8 can be accepted and that these hypotheses fit the sampled data. The hypothesis test revealed the following six latent variables (H1.3-H1.8) that influence "contractor competitive advantages", and their respective standardized regression weights are shown in parentheses: ease of acquisition (0.31), services and maintenance (0.43), technology and innovation (0.30), safety and environmental effects (0.32), compatibility with site characteristics (0.55) and cost (0.34). The standardized regression weights of the latent variables (referred to as factors) and observed variables (called sub-factors) can be normalized to the weights of the relative importance, which are presented in Table 3.

As shown in Fig. 6, "contractor competitive advantages" are measured by the following four latent variables (with their respective standardized regression weights): financial stability (0.85 or 31% of relative importance weight), corporate image and reputation (0.71 or 25%), bid opportunity (0.61 or 22%), and technical capacity (0.61 or 22%).

5. Discussions

The results of this study indicate that six construction equipment selection factors influence contractor competitive advantages. Table 3 presents the ranking of the six selection factors by weight of relative importance, in which the most important factor is compatibility with site characteristics (25%), followed by services and maintenance (19%), costs (15%), safety and environmental effects (14%), ease of acquisition (14%), and technology and innovation (13%). A possible explanation for why the compatibility with site characteristics is the most important factor is that most construction equipment is operated at construction sites and thus must be operable under and compatible with the site conditions (i.e., weather, soil type, surface geography, and re/installation area). Regarding the services and maintenance factor, several survey respondents reasoned that when equipment wears out and deteriorates with operating time, the equipment requires good service and maintenance from manufacturers or vendors to maintain consistent service performance. This service performance helps support the progress of construction projects. However, the technology and innovation factor is the least important of the six selection factors because several respondents' shared the view

Table 3. Factors and Sub-factors with their Weights of Relative Importance

Factors and sub-factors	Standardized regression weight	Weights of relative importance
compatibility with site characteristics	**0.55**	**25%**
– suitability with project-site weather	0.28	22%
– suitability with project-soil conditions	0.21	17%
– suitability with project-surface geography	0.30	24%
– suitability with re/installation area	0.47	37%
services and maintenance	**0.43**	**19%**
– ease of obtaining maintenance tools	0.25	24%
– manufacturer's maintenance services	0.37	36%
– availability of spare parts	0.42	40%
costs	**0.34**	**15%**
– capital cost	0.41	30%
– operating cost	0.39	28%
– maintenance cost	0.34	25%
– displacement cost	0.24	17%
safety and environmental effects	**0.32**	**14%**
– stability and safety	0.30	20%
– hazard protection and alarm system	0.20	13%
– healthy conditions in control room	0.29	20%
– safety system for night operations	0.37	25%
– vibration during operations	0.32	22%
ease of acquisition	**0.31**	**14%**
– various approaches of acquisition	0.46	24%
– popularity and need in market	0.33	17%
– acquisition time	0.50	26%
– time to manufacture and deliver equipment	0.36	19%
– equipment transportation from manufacturer to construction site	0.28	14%
technology and innovation	**0.30**	**13%**
– versatility	0.28	18%
– quality of equipment materials and parts	0.31	20%
– manufacturer's reputation	0.42	26%
– tolerance and operation life	0.30	19%
– continuous research on equipment development	0.27	17%
Total		100%

that new technology and innovative equipment requires a large investment cost, whereas the financial goal of many contractors is to minimize the construction costs and thereby maximize profits. Thus, technology and innovation is not a primary concern.

Regarding the sub-factors related to the cost of equipment, the following are the four most important sub-factors with their respective weights of relative importance: capital cost (30%), operating cost (28%), maintenance cost (25%), and displacement cost (17%). The capital cost sub-factor is ranked as the most important, likely because the financial cost (i.e., cost of capital) accounts for the highest proportion of the equipment cost. The results also revealed another interesting point regarding the weights of sub-factors pertinent to technology and innovation, which fall between 17% and 26%. Among these sub-factors, the manufacturer's reputation is the most important. According to some respondents, the reason for this importance is that inspecting all parts of equipment, which is required during the selection process, is time-consuming and complicated. Thus, the respondents instead relied on the equipment manufacturer's reputation or brand name.

In this study, the sub-factors of financial stability, technical capacity, bid opportunity, and corporate image and reputation were indicators of "contractor competitive advantages". The financial stability sub-factor was found to be the most important, which is potentially because it is unlikely for contractors to fulfill the construction project requirements if their financial status is unsound. Furthermore, any ensuing financial distress could affect their reputation and frequently lead to discontinuity in their business.

6. Conclusions

The selection of appropriate construction equipment plays a vital role in improving contractor competitive advantages. Thus, prior studies have suggested a number of different selection factors. However, these studies did not investigate the influences of different selection factors on contractor competitive advantages, i.e., their causal relationships. This research study therefore attempted to explore these casual relationships by investigating the influences of the construction equipment selection factors on contractor competitive advantages. Through an SEM analysis, six selection factors and their respective weights of relative importance were determined to influence the competitive advantage of the contractors: compatibility with site characteristics (25%), services and maintenance (19%), costs (15%), safety and environmental effects (14%), ease of acquisition (14%), and technology and innovation (13%). In addition, the findings confirmed that construction equipment selection factors influence the competitive advantage of contractors with respect to their financial stability, which had the highest relative importance weight of 31%.

Because the data from this research belong entirely to the construction industry in Thailand, a wider investigation into the construction industries of other countries is recommended to address the country-specific limitation. Nonetheless, this study is the first to investigate the causal relationships between construction equipment selection factors and contractor competitive advantages.

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Appendix 1.

An excerpt of the questionnaire examining factors for "construction equipment selection"

There are factors important to "construction equipment selection". What are the levels of their importance? And what are other factors together with their levels of the importance not written down?

Factors	Sub-factors	Level of Importance Extremely low……………... Extremely high				
		1	2	3	4	5
Functions and capability	dimension and weight	O	O	O	O	O
	power	O	O	O	O	O
	type of fuel	O	O	O	O	O
	type of work done	O	O	O	O	O
	rapidity and movement	O	O	O	O	O
	ease of re/installation and displacement	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Operations and user relations	continuity	O	O	O	O	O
	compatibility with exiting equipment	O	O	O	O	O
	compatibility with other equipment	O	O	O	O	O
	comfort to users	O	O	O	O	O
	suitability with users' ability	O	O	O	O	O
	clear operation view for users	O	O	O	O	O
	ability of recruitment of skill and experience users	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Ease of acquisition	various approaches of acquisition	O	O	O	O	O
	popularity and need in market	O	O	O	O	O
	acquisition time	O	O	O	O	O
	time to manufacture and deliver equipment	O	O	O	O	O
	equipment transportation from manufacturer to construction site	O	O	O	O	O
	ease of storage	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Services and maintenance	ease of obtaining maintenance tools	O	O	O	O	O
	manufacturer's training for users	O	O	O	O	O
	manufacturer's maintenance services	O	O	O	O	O
	availability of spare parts	O	O	O	O	O
	suitability with maintenance personnel's ability	O	O	O	O	O
	ability of recruitment of maintenance personnel	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Technology and innovation	versatility	O	O	O	O	O
	quality of equipment materials and parts	O	O	O	O	O
	manufacturer's reputation	O	O	O	O	O
	tolerance and operation life	O	O	O	O	O
	continuous research on equipment development	O	O	O	O	O
	manufacturing standard	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Safety and environmental effects	stability and safety	O	O	O	O	O
	hazard protection and alarm system	O	O	O	O	O
	healthy conditions in control room	O	O	O	O	O
	safety system for night operations	O	O	O	O	O
	pollutant emission	O	O	O	O	O
	vibration during operations	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Compatibility with site characteristics	suitability with project-site weather	O	O	O	O	O
	suitability with project-soil conditions	O	O	O	O	O
	suitability with project-surface geography	O	O	O	O	O
	suitability with re/installation area	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Costs	capital cost	O	O	O	O	O
	operating cost	O	O	O	O	O
	maintenance cost	O	O	O	O	O
	displacement cost	O	O	O	O	O
	interest, tax, warranty and storage cost	O	O	O	O	O
	savage value	O	O	O	O	O
	others, please specify…	O	O	O	O	O

Appendix 2.

An excerpt of the questionnaire examining factors for "contractor competitive advantages"

There are factors important to "contractor competitive advantages". What are the levels of their importance? And what are other factors together with their levels of the importance not written down?

Factors	Sub-factors	Level of Importance Extremely low…………….. Extremely high				
		1	2	3	4	5
Financial stability	revenue	O	O	O	O	O
	continuous financial credit	O	O	O	O	O
	liquidity	O	O	O	O	O
	profit	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Technical capacity	leadership in technology	O	O	O	O	O
	technology application for developing new working methods	O	O	O	O	O
	low cost leadership	O	O	O	O	O
	high potential to achieve project objectives	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Bidding opportunity	opportunity of receiving bidding invitation	O	O	O	O	O
	opportunity of passing prequalification	O	O	O	O	O
	opportunity of winning bids	O	O	O	O	O
	expected number of engaged projects	O	O	O	O	O
	others, please specify…	O	O	O	O	O
Corporate image and reputation	clients' reliability on contractor firms	O	O	O	O	O
	contractor-reputation ranking	O	O	O	O	O
	expertise in special work	O	O	O	O	O
	leadership in high quality work	O	O	O	O	O
	others, please specify…	O	O	O	O	O

Appendix 3.

An excerpt of the questionnaire examining the influence of "construction equipment selection" on "contractor competitive advantages"

What is the influence of "construction equipment selection" on "contractor competitive advantages"?

The influence of	Level of Influence Extremely low…………….. Extremely high				
	1	2	3	4	5
"construction equipment selection" having on "contractor competitive advantages"	O	O	O	O	O