Contractor Prequalification Model for Lean Project Delivery

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***Abstract*— Waste rates in the construction industry are high and this affects the cost, time, safety and quality of construction projects. Waste occurs through every construction development stage starting from inception, through design, procurement and supply, construction and operation stages. To improve the performance of construction projects, a model is developed to facilitate a more comprehensive implementation of Lean principles starting from contractor or supplier prequalification stage. The model ranks interested contractors or suppliers based on assessing their ability to deliver Lean projects. Factors required for the assessment are extracted from literature, AHP is utilized to compare and rank factors according to their importance. Then the ranked factors are used to score different contractor's ability to deliver Lean projects. The outcome of this model is a ranking of the contractors from the highest Lean practitioner to the lowest based on the total weighted score. To evaluate the model a questionnaire was designed and distributed among different international contractors, the questionnaire asked contractors basic questions about their companies and submittals from each contractor were then evaluated by construction experts. The results show the model's ability to rank contractors according to their pre-established experience in delivering Lean projects. The main contributions of this research are identifying 4 key categories to predict contractors' ability to deliver Lean projects, designing an easy to use scoring system for the identified categories and finally using AHP to merge the categories and the scoring system in a flexible well-structured contractor ranking model.**

Keywords*— *Lean construction, contractor prequalification, AHP, Lean Project Delivery

1. Introduction

The construction industry is slow to adopt new technologies and approaches that improve productivity compared to other industries. This is attributed to several factors which include: safety issues, industry fragmentation, increased regulations, lack of trust among key stakeholders, inadequate process innovation, and culture of craftsmanship [1]. However, continuous productivity improvements in other industries have put pressure on construction stakeholders to find ways of enhancing their productivity. One technique that is being used to improve productivity is applying Lean principles in delivering construction projects. Lean construction is an approach that participants use to identify and eliminate wastes that do not contribute to the value of the final product or service as seen by the client. Lean's proven success stems from the wider perspective of seeing waste, as it is not limited to tangible wastes only, but rather extends to identify less obvious types of waste. These wastes include overproducing, idle time, unnecessary transporting of resources, over-processing, unnecessary storage, unnecessary movement by workers and producing defective products [2].

Successful implementation of Lean principles when delivering a construction project significantly depends on the selected contractor for the project. As contractors do the actual construction, they are in a better position to apply most of the Lean tools. For this to be achieved, more qualified contractors have to be selected and involved in early project stages of a project to understand and alter if necessary the details of project planning and design. The early identification and involvement facilitates a more comprehensive application of Lean tools [3] – [5].

2. Background

Several findings were established through reviewing recent relevant literature. There is plenty of wastage in the construction industry, coming from different sources and there is a pressing need to reduce or

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eliminate as much of this wastage as possible. This could be one of the main efforts to close the gap between the low productivity and efficiency of the construction industry and the productivity and efficiency of the manufacturing industry. One of the promising approaches to address this waste is the Lean Construction approach. The starting point to have a comprehensive application of Lean Construction is to start right, through the prequalification and selection of the correct contractor.

The concept of contractor prequalification is not new or restricted to Lean construction projects. Producing a shortlist of prequalified contractors before bidding is a common practice which helps circumvent some of the limitations of least cost bidding. Accordingly, researchers have exerted considerable efforts towards designing models to prequalify contractors for different projects. Those models differ in the techniques used and the factors addressed based on the application they are built for.

Earlier efforts started by identifying factors to be considered for prequalifying contractors. Examining such factors highlights the fact that the factors to be utilized in each project have to be aligned with the objectives of the project and they differ according to the region and local construction standards. As identifying the factors is only the starting step, later research started building models, using a wide range of techniques, to help owners use the identified factors to assess and prequalify contractors.

As many factors are considered during contractor prequalification, techniques suited for this task are multicriteria decision making techniques. One of the common techniques used in contractor prequalification is Analytical Hierarchy Process (AHP). AHP based models include Ref. [6] model which utilized AHP to organize the identified factors in a structure along with the interested contractors. The final output of this model is a descending ranking of contractors to help clients assess which contractors are qualified to bid for the project. A similar but different model was developed to prequalify contractors for public projects in Athens [7]. The model, also utilizing AHP, included qualitative criteria which were analysed with quantitative indicators to prequalify contractors. A more advanced model that also utilizes AHP was developed to prequalify contractors for public projects [8]. This model identifies and utilizes relevant criteria that is able to separately identify the more qualified contractors for three innovative contracting types, Design-build, cost-plus-time, and warranty. AHP is also used for contract awarding, which is a similar task to prequalification but utilizes different criteria that include the bid price of each contractor. A hybrid model was presented that utilizes AHP and other tools to assess the quantitative criteria such as bid price as well as qualitative criteria related to contractors' performance [9].

An alternative multicriteria decision making technique is Choosing By Advantage (CBA). CBA depends on clearly selecting and identifying criteria that are more able to show the differences between different available alternatives, in this case contractors. This is unlike AHP which defines criteria that are more relevant to the decision being made (in this case performance on project) rather than the competing alternatives [10]. After defining the criteria to be used CBA aims to assess the advantage of each alternative for each of the defined criteria. Several models exist explaining how CBA can be used in the tendering phase of a construction project and the benefits it can bring [11]-[13]. There is no precedence for CBA being applied in an actual project, and there are no models using CBA for contractor prequalification in the pre-tendering phase.

QUALIFIER-2 is a Knowledge based Expert System that aims to help clients prequalify contractors. Presenting many improvements to an earlier version, QUALIFIER-1, this version gives the owner some flexibility in deciding the weights representing the relative importance of different criteria and supports sensitivity analysis of the inputs. Unlike AHP, this model doesn't calculate the weights but assumes users can come up with correct and consistent weights on their own.

Other multicriteria decision making techniques were also used for the purpose of prequalifying or selecting contractors. TOPSIS and VIKOR techniques were used to for selecting contractors [14]. Multiattribute Fuzzy Weighted Average was also used to rank contractors by multiple decision makers [15]. Ref. [16] managed to move from qualitative evaluation to exact optimization of contractor selection, through presenting construction value packaging system (CVPS) which includes a multicriteria approach to contractor selection. Another distinct effort attempted predicting the performance of the contractor on a given project as a separate criteria to be included in the selection criteria [17].Other models utilizing different techniques such as Support Vector Machine (SVM) [18] and Data Development Approach (DDA) [19].

After reviewing relevant literature, multiple models have been reviewed using different techniques. The reviewed models can be divided into two main groups. Models used at the pre-tendering phase to prequalify contractors and models used during the tendering to choose a contractor. Although many similarities exist and techniques can be used for models belonging in both groups, there are two main differences. In the pre-tendering phase there is no offer or contract price in the criteria of choice, instead there are more emphasis on qualitative factors describing contractors' capabilities. The second difference is that in pre-tendering the purpose is to identify a group of qualified contractors, which is achieved through ranking or rating, while in tendering the purpose is to choose one contractor to be awarded the contract.

A few conclusions are drawn after reviewing the literature. The criteria included in each model reflects the focus of the prequalification, they can differ according to the type of owner, the main objectives of the project and the region of the project. The models used a variety of multicriteria decision making techniques varying in complexity and the input needed. The main conclusion that motivated this research is that none of the presented models addressed prequalifying contractors for Lean projects. This requires identifying criteria that can indicate contractors' ability to deliver Lean projects.

3. Model Building and Data Collection

The aim of this research is to build a model for prequalifying contractors for Lean projects. Prequalifying contractors takes place during pre-tendering, which means that there is no bid price to look at and that many of the factors considered to evaluate nominated contractors are qualitative in nature. After reviewing different available tools, AHP is utilized for this study as a multicriteria decision making technique. AHP allows comparing different factors needed for making a decision to establish their weights, which exempts users from having to provide the weights themselves. Using AHP makes it easy and time efficient to explain to different experts how to input their comparisons. This allows soliciting the input of more experts which results in more reliable weights for criteria. AHP also has a detailed approach for detecting any contradictions or inconsistencies that may exists in the input data by experts. Moreover, with some flexibility in the model, it can allow each user to recalculate the weights based on their own preferences. The main limitation of AHP is that it is not an optimization technique, conveniently this doesn't hinder AHP usability for this model, as for prequalifying we are looking to rank candidate contractors and not after choosing the single optimum contractor.

Data collection for the research included two stages. During the first stage, the study utilized literature review and a questionnaire sample survey, both aimed to identify and prioritize the factors that should be assessed to prequalify contractors to deliver Lean projects. During the second stage, data in the form of technical submittals was collected from different contractors to be used for the case study. Sample questions were distributed to different construction companies, with at least one of them being a construction company that implemented lean construction principles in their operations.

The factors identified in this research were gathered based on a comprehensive literature review, the factors address Lean Construction as identified by industry experts within Lean Construction field, while focusing on the areas of weaknesses that Lean Construction have. Many factors could be looked at to evaluate a contractor's ability to deliver Lean projects. For the ease of use and to avoid building a model that needs too much input data to run, Lean factors considered are summarized into fewer categories. The following categories: customer focus, culture/people, waste elimination, workplace organization and standardization and continuous improvement/built in quality were used before by Ref. [20]. However, for this research, continuous improvement was categorized under culture/people taking into account that continuous improvement is required through the project life cycle in various areas such as labor management, quality procedure, equipment productivity and material wastage management.

Therefore, for the ease of comparison between contractors the factors selected for this research were categorized into the following main four categories: Customer (client) focus, waste elimination, culture/people and workplace organization and standardization. These factors are the main criteria for assessing contractors' ability to deliver Lean projects.

These factors to be used in prequalifying contractors for Lean Construction projects are compared in pairwise comparisons using a 9-point scale. This scale is used to allow experts to compare pairs of different factors in terms of their importance in indicating contractors' ability to deliver Lean projects. The selected factors are compared in pairs ranging from equally important with a scale of 1 to extremely more important with a scale 9. The 9 point scale introduced by Ref. [21] is shown in Table 1.

Table 1. Scales for Pairwise Comparison [21]

Intensity of Importance	Description	Explanation
1	Equal Importance	Two activities contribute equally to the object
3	Moderate importance	Experience and judgment slightly favour one activity over another
5	Strong importance	Experience and judgment strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another
9	Extreme importance	The favouring of one activity over another is of the highest possible order of affirmation

4. Establishing Weights

The comparisons are implemented in an automated spreadsheet that can be changed and modified by the user. This provides flexibility as any user/client selecting a contractor for a construction project can revise the comparisons to match the user's or project's objectives. The entries are then formulated as a matrix as shown in below. The next step is to normalize the matrix. The average of each row in the normalized matrix is the weight of the factor on the left column.

$$A = \begin{pmatrix} a11 & a12 & \dots a1j & \dots a1n \\ ai1 & ai2 & \dots aij & \dots ain \\ an1 & an2 & \dots anj & \dots ann \end{pmatrix} = (a_{ij})\, n \times n \quad (1)$$

Where: A is pairwise comparison matrix, a_{ij} is relative importance of alternative/decision criteria "i" compared to alternative/decision criteria "j" and n is the number of alternatives in the set.

The last step in building an AHP model is to check for the consistency of the comparisons. A consistency check was carried out for the pairwise comparison using the following equations:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{i^{th}\, entary\ in\ AW^T}{i^{th}\, entary\ in\ W^T} \quad (2)$$

Where: λ_{max} is the maximum Eigen value, A is the pairwise comparison matrix, and n is the number if matrix and W is the weight vector. The consistency index can be defined using the following equation:

$$CI = \frac{\lambda \max - n}{n-1} \quad (3)$$

The consistency ratio can be calculated using the following equation:

$$CR = \frac{CI}{RI} \quad (4)$$

The value of CI then compared to the Random Index (RI) presented in Table 2 below, if the CR >10%, the matrix is not consistence, therefore, the comparison need to be checked and verified, if CR≤10% then the matrix considered acceptable. The steps of building the prequalification model are illustrated in Figure 1.

Table 2. Random Index for Different Value of n [21]

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

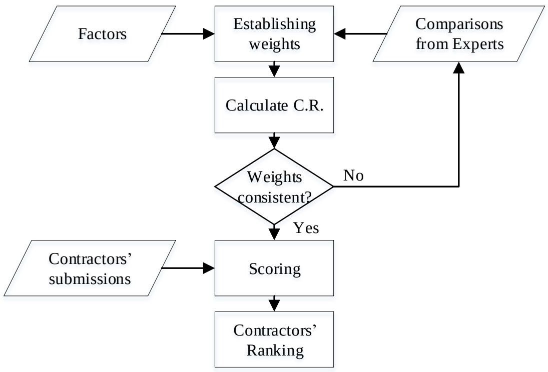

Figure 1. AHP Process Flow Chart

5. Designing Scoring System

After establishing weights for factors representing each factor's relative importance when ranking contractors based on their ability to deliver Lean projects, the following step is to set a scoring system to be able to give each contractor a score for each factor and a total score out of 100. Each one of these factors are scored using a scale from 1 to 10 in a rubric style assessment, where scale 1 – 3 presents below expectation, 4 – 6 presents meets expectations and 7 - 10 presents exceeds expectation.

The evaluation of each category is based on the frequency of applying one or more of the tools serving Lean principles such as value engineering, people training and development, Just in Time delivery (JIT) and waste elimination in terms of time, cost and material [20]. It is left to the user to utilize his experience with the given scoring guide to score each contractor for each factor within the given range. Although this scoring, shown in Table 3 is still subjective, yet it provides a well-structured and clearly communicated scoring system that promotes consistency.

6. Case Study

A case study was presented to showcase how the developed contractor prequalification model works and to validate the model's output. The case study includes two stages. The first stage was related to building the AHP model where experts were asked to compare different factors using 9-point scale. These comparisons were used to establish each factor's weight. The second stage was related to using the AHP model. Technical qualifications submissions were collected from a number of contractors and used for scoring in order to test the model ability to give a higher priority to the contractors that already know how to deliver Lean projects.

The comparisons of the factors included in the model were carried out by technical directors and project managers within the construction field. The results indicated that waste elimination was considered the most influential factor with total weigh of 59%. Customer focus comes second with a total percentage of 22% and each culture/people and workplace organization and standardization with equal percentages of 9%. The consistency of the matrix was checked through calculating CI and CR, the value of CR for the model was 6% which is less than 10%. This indicates that the comparisons carried out by experts are of acceptable consistency. The weighted score of each factor is presented in Table 4 below.

A questionnaire addressing lean principles was distributed to seven preselected international construction companies. Each contractor was given a clear description of the purpose and a summary of the outcome of this research. The selected contractors for this research represented contractors in tunnel construction, Mechanical, Electrical and Plumping (MEP) and general contractors (GC). The questionnaire comprised of 4 questions to compare varied factors to establish their relative importance from the contractor's own perspective. Responses from 3 contractors were received. Each contractor's submission was assigned a score from 1 to 10 based on matching provided details of his previous projects with the scoring criteria in Table 3. A higher score was assigned to the contractor with project experience in mega projects as these projects are more complicated and have bigger budgets and longer durations. The resulting scores were converted to percentage by multiplying the score of each factor with the weight score of that factor to calculate the average weighted score. The results of ranking score for the submission received from each contractor are summarized in Table 5 below.

Table 3. Factor Scoring

	Below expectation (1 – 3)	**Meets expectation (4 – 6)**	**Exceeds expectation (7 – 10)**
Customer Focus	The contractor is un-able to present a sound and clear understanding of customer focus, and has no previous experience in applying value engineering.	The contractor provides a good record of experience in understand customer focus and apply value engineering. The contractor has previous experience with up to 3 projects or one large scale construction projects.	The contractor provides an exceptional record of experience in customer focus and applying value engineering in more than 3 previous projects or provide an experience within more than one large scale construction project.
Waste elimination	The contractor is un-able to represent a clear understanding of waste elimination techniques or to provide an example of one waste elimination technique.	The contractor shows an understanding of waste elimination techniques and how they are applied through project. The contractor can provide record of experience which includes the effective application of more than technique of waste elimination and how they managed the waste on site.	The contractor shows a good understanding of waste elimination through different applications such as JIT delivery, increasing prefabrication and ergonomic problems.
Culture/ people	The contractor is unable to present any training for the people in work operations or not providing any quality control procedure.	The contractor is un-able to represent records of experience showing his willingness to educate and train the workers and employees in one area such as safety, management and technical aspects.	The contractor shows clear understanding of the importance of training the people through providing a record of completed training and continuous learning development.
Workplace organi-zation and standardi-zation	The contractor is un-able to submit any previous project experience which may include logistic, work process or site plan drawings.	The contractor submits evidence showing clear understanding of workplace organization through up to 3 project experiences of logistic process and work processes supported with previous drawings and/or forms.	The contractor submits records of experience reflecting clear understanding of workplace organization through more than 3 project examples of logistic process and work processes.

Table 4. Factor's Weights

	Weighted Score (%)
Customer Focus	21.9
Waste Elimination	59.3
Culture/People	9.4
Workplace organization and Standardization	9.4
Total	100%

The results in Table 5 indicated that contractor 2 achieved the highest score. This is consistent with what was expected, as it was known that contractor 2 is the contractor that has experience in delivering Lean Projects. It should be noted that the results presented in Table 5 above were based on the information submitted by the contractors. These numbers can be varied between contractors based on the quality of information provided.

Table 5. Contractors Ranking Score

	Contr-actor #1	Contr-actor #2	Contr-actor #3
Customer Focus (22%)	6	9	4
Waste Elimination (59%)	6	6	5
Culture/ People (9%)	8	5	3
Workplace organization and standardization (9%)	4	5	6
Total Weighted Score out of (100%)	60%	65%	47%

7. Conclusion

The aim of this research is to provide a well-structured model for prequalifying contractors for delivering Lean projects. To achieve this aim a number of domains had to be reviewed, including reviewing the history of Lean Construction; reviewing factors indicating a contractor's ability to deliver a Lean project, reviewing multicriteria decision making techniques and reviewing designing rubric style scoring systems.

The review of these domains resulted in designing a multicriteria model for prequalifying contractors for delivering Lean projects. Designing the model brings a number of key contributions that can be listed as follows:

1- Through reviewing the existing literature and designing, distributing and analysing surveys, the key factors indicating a contractor's ability to deliver Lean projects were identified. These factors include customer focus, waste elimination, culture/people and workplace organization and standardization.

2- AHP was identified as the most suitable multicriteria decision making tool, and hence was utilized to compare the identified factors and to establish weights reflecting each factors importance.

3- A scoring system was designed to allow the owner to give a score for a contractor to reflect the contractor's ability to deliver a Lean project.

4- The weights and scoring system are merged together in a contractor prequalification model. The model is easily adjustable to fit clients' specific needs for different projects. Building an adjustable model holds significant importance as each construction project is unique and therefore the contractor selection factors must be fine-tuned according to specific needs for each project.

Through analysing a case study, results indicated that waste elimination was considered the most crucial factor with total percentage of 59%, customer focus with total percentage of 22% and each culture/people and workplace standardization with equal percentage of 9%. Contractors' submission were used to give a score and rank contractors using the AHP weights and accompanying scoring system. The developed prequalification model was able to identify the contractor that was already known to have the most experience in delivering Lean projects.

Due to various constraints, it was not possible to reach many companies and individuals who have applied Lean Construction to improve the quality of data and information collected. Having a bigger sample size will pave the way for fine tuning the factors identified and their weights and better articulating the scoring rubric. The quality of results obtained is largely dependent on the cooperation of the questionnaire respondents and interviewees who participated in the study. The factors established will not give a quantitative measure of potential benefits that will be achieved by implementing the criteria. This implies that the actual benefits can only be known after completion of the project. Final limitation is that the given score is quantitatively based on the contractor's submissions, but when it comes to evaluating the quality of contractor's submitted records of experience, a subjective qualitative approach is adopted.

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