A Framework for Identifying and Measuring Competencies and Performance Indicators for Construction Projects

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ABSTRACT

In contemporary construction environments, employees and managers alike are faced with numerous pressures to carry out work to meet corporate expectations of performance. Continuous change and adaptation in organizational structures, practices, and technologies are conducive to successful management and execution of construction projects. Construction projects tend to measure how well they perform against a set of predefined performance indicators. These performance indicators are based on the ability of construction projects to attain necessary sets of “competencies” that enable successful execution of work. This paper identifies and classifies the different competencies and performance indicators that are used in construction projects and proposes a framework and methodology to identify and measure them. Appropriate measurement scales for the different competencies and performance indicators are developed, and a survey structure is proposed to collect data on the competencies and performance indicators from experts in the construction domain. A data aggregation method is introduced to combine experts' evaluation of construction projects' competencies and performance indicators. Lastly, the paper discusses future work pertaining to the development of a cascade fuzzy neural network that can predict different performance indicators for construction projects based on the identified competencies.

INTRODUCTION

Construction projects rely on competencies related to their human resources to ensure successful execution of work. For example, the ability to obtain highly skilled employees is vital for better project performance. However, quantification of employees' competencies has been limited to the investigation of competencies in terms of training and formal education, thereby ignoring other qualities such as standards and management practices that might better assess relevant competencies and ensure better performance (Nybo 2004). Until now, an interpretation and mapping of why and to what extent performance indicators have improved or declined had yet to be investigated.

Competencies are defined as “A combination of motives, traits, self-concepts, attitudes or values, content knowledge or cognitive behavioural skills; any individual
characteristic that can be reliably measured or counted and that can be shown to
differentiate superior from average performers” (Spencer et al. as cited in Shippmann
et al. 2000, 706). In the context of this study, competencies are divided into two main
categories: technical and behavioural competencies. Technical competencies are
defined as “firm specific technologies and production related skills” (Walsh and
Linton 2001, 167) developed at the company level and implemented on its
construction projects, such as project management practices. On the other hand,
behavioural competencies are defined as “a mixture of knowledge, skills, abilities,
motivation, beliefs, values, and interests” (Fleishman et al. as cited in Shippmann et
al. 2000, 706) possessed by individual workers, such as project management
knowledge and experience, and transferred to the construction project to improve its
performance (the process of measuring progress against predetermined objectives).

This paper proposes a framework and methodology that identifies different
competencies and performance indicators necessary for the successful execution of
construction projects. This paper focuses on competencies at the project level, rather
than the organizational level, where organizational competencies are manifested in
the production related practices and skills acquired and executed on the project level
to ensure better performance. Furthermore, a data collection survey structure and an
aggregation method are also proposed as prerequisites for developing a cascade fuzzy
neural network to evaluate competencies and predict different performance
indicators. The following section highlights previous research conducted in the area
of competencies in construction projects to identify the gaps in previous research.

BACKGROUND AND PROBLEM STATEMENT

Past research has primarily addressed competencies in construction by
defining competency as performance (Fayek 2012); it thus has failed to sufficiently
investigate the relationship between construction competencies and performance
indicators. Furthermore, previous research in competencies and performance in the
construction domain (Markus et al., 2005, CII, 2005; Alroomi et al., 2011) indicated a
need for a standardized framework and methodology to: (1) develop a standardized
hierarchy and list of different competencies and performance indicators for
construction projects, (2) identify critical competencies, and (3) identify and map the
relationship between these competencies and different performance indicators for
construction projects. An overview of some of the previous work conducted in the area
of competencies is summarized below.

Sparrow (1995) integrated the different concepts of competencies at different
levels within an organization. A management competency approach was introduced
by Sparrow to measure effectiveness across different organizational sectors, and a
behavioural competency approach was applied within an organization to measure
individual competencies. Sparrow established an important definition for technical
competencies as something owned by an organization and transferred or granted to
individuals working in the organization.

Markus et al. (2005) identified three approaches for modeling competencies:
the educational approach, the psychological approach, and the business approach.
The educational approach is based on the functional role of analysis based on “role
outcomes, or knowledge, skills and attitudes, or both, required for role performance”
(Markus et al. 2005, 117). The psychological approach is based on identifying competencies based on “the skilled behavioural repertoires of recognized star performers within particular organizations” (Markus et al. 2005, 118). The business approach is most relevant to the construction domain, wherein inputs to the competency model consist of “competencies for competitive advantage, including core competencies, capabilities, and practices; outputs of a business-based competency model” (Markus et al. 2005, 118) are measured in terms of performance indicators such as profitability to assess organizational performance.

Alroomi et al. (2011) proposed a core-competency framework and methodology to measure and prioritize the competency of cost estimators in construction projects. This study was conducted through combining the effects of the level of importance of each competency and its associated gap between the ideal and actual level of competency. Twenty-three core estimating competencies were identified and classified into skills, knowledge, and personal attributes.

Research conducted in the area of competencies indicates a need to investigate the different competencies, their measurement, and their relationships to performance indicators for construction projects. The existing body of knowledge provides a solid foundation for competencies identification (CII, 2005; Caupin et al. 2006); however, further investigation is required to categorize and measure competencies necessary for construction projects in different industries to perform well. This paper examines construction projects' competencies by proposing a framework and methodology, described in the following section, which aims to identify and measure different construction projects' competencies and map them to performance indicators.

RESEARCH FRAMEWORK AND METHODOLOGY

During the Identification Phase, competencies and performance indicators for construction projects are identified, and an appropriate measurement scale is developed for each. Next, in the Data Collection Phase, a data collection survey structure is developed as a prerequisite for collecting expert input regarding the different competencies and performance indicators. In the Data Aggregation and Model Development Phase, an aggregation method is introduced to provide an overall value for the collective agreement of experts towards the different identified competencies and performance indicators; a cascade fuzzy neural network to predict performance indicators will be developed in future. A hypothetical example is presented to illustrate the application of the aggregation method to combine experts’ feedback for different competencies.

Identification Phase

Competencies Structure

A range of competency guidelines and construction industry standards of typical competencies were investigated and identified in the literature review stage of this study to categorize competencies for construction projects (Arditi et al 2000; Kululanga et al. 2001; Markus et al. 2005; CII, 2005; Caupin et al. 2006; Alroomi et al. 2011). The hierarchy of these competencies is divided into technical and behavioural competencies (Figure 1). In the hierarchy proposed in this paper,
technical competencies are classified as either internal or external technical competencies. Internal technical competencies are further divided into: 1) practices that better construction project performance (e.g., contract administration practices, financial auditing practices, innovation practices, and workforce improvement practices) or management practices (e.g., scope, change, and risk management practices) that assist in identifying project participants’ roles and responsibilities and enhancing the execution of the work, and 2) operational competencies, including the application of new technologies (e.g., building information modeling), that contribute to better use of resources. External technical competencies include those which relate to how a construction project relates to stakeholders outside of the construction organization; for example, the communication with stakeholders’ competency focuses on the ability of construction project employees to communicate with different construction market stakeholders.

![Figure 1. Proposed construction project competencies hierarchy](image)

**Figure 1. Proposed construction project competencies hierarchy**

Behavioural competencies, on the other hand, are classified as knowledge, skills, or personal attributes (Alroomi et al. 2011). For example, the decision making competency for workers is a knowledge related competency that contributes to the execution of work in construction projects. The learning competency is a personal attribute related to a behavioural competency that positively enhances productivity within construction projects. Finally, the leadership competency is a personal skill that enhances the overall performance of work in construction projects.

**Performance Indicators**

In construction projects, performance indicators are used to evaluate how well a construction project is progressing. Several performance measurement frameworks, such as Key Performance Indicators, the Balanced Scorecard, and the European Foundation for Quality Management Excellence Model, have been used by previous researchers to measure performance (Bassioni et al. 2004). However, most of the proposed competency and performance measurement models in existing literature are conceptual and have not been validated with actual data (Kaplan and Norton 1992; Kagioglou et al. 2001; Bassioni et al. 2004).

Several categories of performance indicators are identified in this research. Table 1 provides some of the categories and lists performance indicators within each category (Kagioglou et al. 2001; Bassioni et al. 2004).
Table 1. Sample performance indicators for construction projects

<table>
<thead>
<tr>
<th>Performance Indicator Category</th>
<th>Performance Indicator</th>
<th>Measurement Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financial Performance Indicators</td>
<td>Growth Rate</td>
<td>Percentage (%)</td>
</tr>
<tr>
<td>Technical Performance Indicators</td>
<td>Reported Safety Incidents</td>
<td>Numerical Value</td>
</tr>
<tr>
<td>Market Performance Indicators</td>
<td>Stakeholders’ Satisfaction</td>
<td>Subjective Scale</td>
</tr>
</tbody>
</table>

Measuring Competencies and Performance Indicators

Competency and performance indicator measures are further divided into sets of evaluation criteria that can be captured through different construction experts and collected from construction projects either quantitatively or qualitatively. For example, communication management is identified as one of the qualitative technical management practices competencies. The communication management competency has three main evaluation criteria: 1) updating of policies and procedures to implement and monitor practice, 2) application of policies and procedures to practice, and 3) communication system upgrades. Like construction project competencies, performance indicators are identified based on previous research (Kaplan and Norton 1992; Bassioni et al, 2004) and are divided into qualitative and quantitative measures.

Previous research was investigated to determine appropriate measurement scales for the different competencies (Arditi et al 2000; Caupin et al. 2006; Alroomi et al. 2011; Kang et al. 2013). Numerical scales are assigned to measure quantitative competencies and performance indicators. For example, a numerical scale is assigned for the number of similar projects previously executed as part of the experience behavioural competency. Performance indicators such as growth rate are assigned a numerical scale indicating the percentage of growth compared to a previous year.

Table 2. Measurement scales: Qualitative competencies/performance indicators

<table>
<thead>
<tr>
<th>Scale Type</th>
<th>Scale Value</th>
<th>Scale Description</th>
<th>Competency/Performance Indicator Evaluation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance Rating Scale</td>
<td>1</td>
<td>Extremely unimportant</td>
<td>Criterion 1</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Unimportant</td>
<td>Criterion 2</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Slightly unimportant</td>
<td>Criterion n</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Neither unimportant nor important</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Slightly important</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Important</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Extremely important</td>
<td></td>
</tr>
<tr>
<td>Implementation Rating Scale</td>
<td>1</td>
<td>Never implemented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Rarely implemented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Sometimes implemented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Frequently implemented</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Always implemented</td>
<td></td>
</tr>
</tbody>
</table>
For measuring qualitative competencies and performance indicators, two types of scales are identified. The first scale is a seven-point importance rating scale to identify the importance and relative weight of each of the evaluation criteria, while the second scale is a five-point degree of implementation rating scale to identify the degree of application or implementation of a given competency or performance indicator on a construction project. Table 2 above displays the two types of scales assigned to the different qualitative competencies and performance indicators that are evaluated based on a set of \( n \) evaluation criteria. Table 3 below displays a sample of data collected for *communication management* competency.

**Table 3. Communication management competency scale values**

<table>
<thead>
<tr>
<th>Scale Type</th>
<th>Competency Evaluation Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Updating of policies and procedures to implement and monitor practice</td>
</tr>
<tr>
<td>Importance Rating Scale</td>
<td>6—Important</td>
</tr>
<tr>
<td>Implementation Rating Scale</td>
<td>2—Rarely implemented</td>
</tr>
<tr>
<td></td>
<td>Application of policies and procedures to implement and monitor practices</td>
</tr>
<tr>
<td>Importance Rating Scale</td>
<td>7—Extremely important</td>
</tr>
<tr>
<td>Implementation Rating Scale</td>
<td>4—Frequently implemented</td>
</tr>
<tr>
<td></td>
<td>Communication system upgrades</td>
</tr>
<tr>
<td>Importance Rating Scale</td>
<td>5—Slightly important</td>
</tr>
<tr>
<td>Implementation Rating Scale</td>
<td>2—Rarely implemented</td>
</tr>
</tbody>
</table>

**Data Collection Phase**

Following the identification of the different measurement scales described earlier in this paper for competencies and performance indicators, a survey structure is proposed to collect the required information for measuring the different competencies and performance indicators. The survey includes three main sections. The first section identifies information about the construction project in terms of its scope of work and size of project. The second section captures information pertaining to the different quantitative and qualitative technical and behavioural competencies. The third section aims to collect information about the different qualitative and quantitative performance indicators. Once the survey is developed, a group of construction experts with varying levels of experience and positions will validate the contents of the survey. Additionally, a pilot project will be identified for the study, where different personnel working on this pilot project will be interviewed. Once the pilot project is complete, a data collection phase will commence to collect data to develop a model capable of predicting performance indicators based on the different competencies identified in this research.

**Data Aggregation and Model Development Phase**

The objective of this phase is to aggregate an expert’s opinions regarding the evaluation criteria of the different competencies and performance indicators into one value that represents that competency or performance indicator. Use of the Ordered Weighted Averaging (OWA) aggregation operator (Yager 1998) is suggested to aggregate different experts’ opinions, as it captures the exact values that represent the
degree to which a competency’s or performance indicator’s evaluation criteria are all satisfied (Yager 1998; Xu 2006).

An aggregated value of the evaluation criteria for both the qualitative competencies and performance indicators can be achieved by applying OWA through a three step procedure: (1) determine the OWA weights and create a weight vector; (2) reorder the evaluation criteria’s assigned degree of implementation rating scale values in descending order for each expert; and (3) multiply these ordered rating scale values by the predetermined weight vector. Assume a sample of three construction expert responses for the communication management competency evaluation criteria are collected. The data are analyzed, and a Relative Importance Index (RII) is calculated—as shown in Table 4—based on the participants’ feedback regarding their expectations of the importance of the evaluation criteria for the communication management competency. For example, the RII for “updating of policies and procedures to implement and monitor practice” can be calculated using Equation (1):

Relative Importance Index (%) = \( \frac{n_1 + 2n_2 + 3n_3 + 4n_4 + 5n_5 + 6n_6 + 7n_7}{7(n_1 + n_2 + n_3 + n_4 + n_5 + n_6 + n_7)} \times 100 \)  \( (1) \)

Here, \( n_1 \) to \( n_7 \) are the number of respondents who selected the different importance scale values of 1 to 7 respectively. For example, the RII for the “updating of policies and procedures to implement and monitor practice evaluation” criteria is shown in Equation (2), where one expert rated its importance as 5, one rated it as 6, and one rated it as 7:

\[
RII = \frac{(5 \times 1) + (6 \times 1) + (7 \times 1)}{(1 + 1 + 1)} = 85.7
\]  \( (2) \)

Table 4. Relative importance index and relative weight for communication management competency

<table>
<thead>
<tr>
<th>Evaluation Criteria Description</th>
<th>Relative Importance Index (RII)</th>
<th>Relative Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Updating of policies and procedures to implement and monitor practice</td>
<td>85.7</td>
<td>0.42</td>
</tr>
<tr>
<td>Application of policies and procedures to monitor practices</td>
<td>74.2</td>
<td>0.38</td>
</tr>
<tr>
<td>Communication system upgrades</td>
<td>42.2</td>
<td>0.20</td>
</tr>
</tbody>
</table>

A relative weight \( w_i \) is then calculated for each of the competency evaluation criteria, listed in Table 4, and calculated using Equation (3):

\[
Relative \ Weight = \frac{RII_i}{\sum_{i=1}^{n} RII_i} \quad (3)
\]
Where $RIL_i$ is the relative importance index for a competency evaluation criteria $i$, and $\sum_i RIL$ is the summation of the relative importance indices for the different evaluation criteria pertaining to a given competency. For example, the weight of the “updating of policies and procedures to implement and monitor practice” evaluation criteria is calculated as in Equation (4):

$$\text{Relative Weight} = \frac{0.87}{0.87 + 1.43 + 1.42} = 0.42 \quad (4)$$

Once the relative weights for the different competency evaluation criteria have been computed, then each expert’s evaluation provided for the “degree of implementation” rating scale is tabulated as shown in Table 5. The set of values that each expert provides comprise a tuple set. For this illustrative example, the three values (the degree of implementation rating scale values for each of the three evaluation criteria for the communication management competency) are provided by each of the experts and are pooled into three three-tuple sets. These tuples each represent the three evaluation criteria for the communication management competency, denoted by $(c_1, c_2, c_3)$.

**Table 5. Experts’ degree of implementation rating for communication management competency**

<table>
<thead>
<tr>
<th>Expert</th>
<th>Evaluation Criteria 1 $(c_1)$</th>
<th>Evaluation Criteria 2 $(c_2)$</th>
<th>Evaluation Criteria 3 $(c_3)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
</tbody>
</table>

It is important to highlight the re-ordering of the experts’ input—a vital step of the OWA method, as shown in Table 6. An aggregate $c_i$ is not associated with a particular weight $w_i$, but rather a weight is associated with a particular ordered position of aggregate (Yager 1998).

**Table 6. Ordered experts’ degree of implementation ratings for communication management competency**

<table>
<thead>
<tr>
<th>Expert</th>
<th>Evaluation Criteria 1 $(c_1)$</th>
<th>Evaluation Criteria 2 $(c_2)$</th>
<th>Evaluation Criteria 3 $(c_3)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>4</td>
<td>3</td>
</tr>
</tbody>
</table>

The following steps are then followed to aggregate each expert rating value. First, a weight vector is developed for the different evaluation criteria based on the relative weights previously calculated and presented in Table 4:
Each expert’s degree of implementation rating score is then arranged in a descending order (Table 6), where values provided by experts are grouped into a three-tuple set. For example, the tuple set for expert 1 is (5, 5, 4). An aggregated value for each expert score for the different evaluation criteria for the communication management competency is then provided using Equation (5), where, $\mathbf{w}_c$ is the aggregated expert value for the set of competency evaluation criteria, $b_i$ is the $i^{th}$ largest element of the ordered tuple:

$$\mathbf{w}_c = \sum_{i=1}^{n} w_i b_i$$  \hspace{1cm} (5)

Finally, the different evaluation criteria values provided by each expert (e.g., Expert 1) are combined into a single aggregated value using Equation (5), as shown in Equation (6):

$$\begin{bmatrix} 0.42 \\ 0.38 \\ 0.20 \end{bmatrix} \begin{bmatrix} 5 \\ 5 \\ 4 \end{bmatrix} = 0.42 \times 5 + 0.38 \times 5 + 0.20 \times 4 = 4.82 \hspace{1cm} (6)$$

According to the calculations in Equation (6), the score Expert 1 assigned to the communication management competency (expressed in the three competency evaluation criteria described in Table 4) is 4.82 out of 5.00. Similarly, aggregated values for experts 2 and 3 are calculated to be 4.42 and 4.22 respectively. The aggregated values in this example indicate that the degree of implementation of the communication management competency lies between 4 (Implemented) and 5 (Frequently Implemented). A cascade fuzzy neural network will be developed to map the relationships between the different construction project competencies and performance indicators. Sets of actual input data (aggregated competency evaluation criteria) and output data (performance indicators) will be collected from different construction projects to train the cascade fuzzy neural network to improve its accuracy and reliability.

CONCLUSION

A framework and methodology were presented in this paper to identify and measure different competencies and performance indicators for construction projects in different industries. Measurement scales were identified to measure competencies and performance indicators. A data collection survey structure was proposed to gather the required data for competencies and performance indicators in construction projects. An aggregation method (OWA) was presented, along with an illustrative example, to combine experts’ opinions of different evaluation criteria used to measure different qualitative competencies and performance indicators. Future work will involve the development of a more advanced application of the OWA aggregation method to combine both qualitative and quantitative criteria. A cascade fuzzy neural network will be developed to map the relationships between the different
construction project competencies and performance indicators and to use the competencies to predict project performance.

REFERENCES


