Development of quality function development matrix to measure the quality management performance of contractor

ZHANG Bei-bei†, CHENG Hu
Project Management Research Institute, Southeast University, Nanjing 210096, P. R. China

Received 6 March 2011; received in revised form 19 April 2012

Abstract: Quality function development (QFD) matrix was introduced as a tool to measure the quality management performance of contractors. Engineering quality, quality management system components, and their relationship were defined. An integrated engineering quality system was decomposed into seven factors and the quality management system was composed of eight factors. Importance weights of all factors and their relationship point were acquired by questionnaires and interviews. Then, QFD matrix was formulated and the calculating process was proposed. This model was verified on a case study. The result shows that it is useful for contractor in benchmarking themselves and invaluable for owners in the process of deciding contractor.

Keywords: quality function development matrix; engineering quality; quality management system; quality performance

1 Introduction

The construction industry shows a rapid pace in 21st century. Quality management systems (QMSs) are being operated in some sectors in China but it is rare to meet these systems in construction industry. Within the construction industry, the implementation of QMS is slow. There are many hindrances that make it difficult to apply QMS effectively due to the nature of construction. A construction project is usually a unique collection of people, equipment, and materials brought together at a unique location under unique weather conditions, while most manufacturing is a system of mass production wherein all of these factors are consistent with producing typical products over and over again. Commonly perceived construction-specific features make construction industry different from other industries and make contractors hard to implement QMS.

It is difficult to bring the function of QMS into full play without measuring its effectiveness or effect. Many discussions appeared on the effectiveness of QMS in construction industry in recent years. Quality function development (QFD), a critical quality management technology, was introduced in measuring the quality performance of construction corporate quality, construction project quality and construction product quality by defining the relationship between quality factors and performance factors [1-3]. A quality matrix was proposed by Öztaş et al. [4] to measure the effectiveness of QMS in Turkey construction industry. Lee et al. [5] introduced an automated tool named stochastic QFD system integrated stochastic simulation modeling and traditional QFD technology, which measures the quality performance of a design/build contractor. However, there is no accurate, unified and objective way of measuring the effectiveness or performance of quality management of contractors in construction industry.

We developed a QFD matrix based on the previous research for measuring the quality management
effectiveness of contractors. The research included the determination of a method to implement QFD matrix and a case study to verify the model.

2 Definition of variables

For analyzing quality management performance of contractor, engineering quality factors and QMS factors should be defined.

2.1 Engineering quality factors

The construction industry is predominantly project based and quality is one of client’s prime concerns in their construction projects. Quality is an essential element for sustainability and customer satisfaction. Within three traditional goals of the project, both duration and cost can be measured with specific figures, but quality is a vague variable that can not be measured quantitatively [6].

With particular reference to the construction industry, quality is defined as: 1) fitness for a required standard, which provides customer satisfaction and value for money [7]; and 2) meeting the legal, aesthetic and functional requirements of a project [8]. Based on the emphasis of work relating to interdependency of the people/building/environment systems, the framework for identifying attributes of satisfaction of housing quality, which established by Liu [9], includes physical comfort, health, safety, functional appropriateness, psychological comfort, psychological safety, aesthetics, privacy, security, image/status, community, and space conservation. Lee and Arditi [3] held that building quality factors should includes performance, usability, dependability, conformance, safety, economics, aesthetics, and perceived quality. Life cycle theory requires quality objective pursuit of unification of function, services, technical standards, security, and so on [10]. A new conception of engineering quality, namely, life-cycle inter-subjective quality of construction project was put forward by Chen [11]. Based on the concept of scientific development experience, Yao [12] proposed a new concept system of construction quality combined the qualities of structure, function, charm and sustainability.

Engineering quality is not only the fitness of requirements of contract, laws and regulations, but also the reflection of the needs of resources conservation, environmental protection and sustainability. Therefore, a new integrated quality system should be constructed to reflect the whole requirements for all stages in life cycle and all participants. Seven indexes for new engineering quality along with their brief descriptions are presented in Table 1.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural integrity</td>
<td>The degree of fulfillment of mandatory structural requirement of laws and regulations in order to keep the stability and reliability of building. It can be measured by structural durability, disaster prevention capabilities, safety and reliability.</td>
</tr>
<tr>
<td>Functional adequacy</td>
<td>The measure to which the primary operating characteristics and functions of the building components meet the building users’ basic functional and reasonable technical needs such as usability, convenience and intelligence.</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>The level of satisfaction the building users experience with the appearance and feel that the building provides. It emphasizes the shape feature, esthetics trait and whether it is in harmony with the surroundings.</td>
</tr>
<tr>
<td>Economic</td>
<td>Adequate total construction cost, minimal maintenance cost, and expediting cost keep in parallel with the life cycle of building.</td>
</tr>
<tr>
<td>Conformance</td>
<td>The degree to which the building product and its individual components fulfill the design standards, specifications and regulations which include the stated and/or implied needs of user and requirement of society that is resulted from laws, regulations, rules, codes, statues, and other considerations.</td>
</tr>
<tr>
<td>Customer satisfaction</td>
<td>The level of satisfaction the building users experience with the whole building.</td>
</tr>
<tr>
<td>Ecologic quality</td>
<td>The degree to which the pollution and damage to environmental and ecosystems is limited to a minimum level.</td>
</tr>
</tbody>
</table>
2.2 QMS factors

In construction projects, quality performance of contractors is considered as vital for client satisfaction. ISO9000 certifications related to construction are popular in several countries and ISO9000-based QMSs have been widely adopted in construction industry.

The majority of contractors were reportedly led into ISO9000-based QMSs mainly by client initiated mandatory requirements for contractor selection. It is also chose by some contractors themselves in anticipation of various tangible and intangible benefits such as reduction of rework and wastages, and improvements in documentation and marketing tool.

Several studies conducted by various researchers outlined significant benefits from QMS including

1) costs, wastages, and rework reduction;
2) maintaining competitiveness and improving customer satisfaction;
3) standard processes, structured documentation procedures and better control; and
4) less conflicts, claims and disputes.

As the ISO9000 quality management is one of the most widely accepted models due to its excellent performance, components of a corporate QMS were modified from ISO9000 quality management standard requirements. Eight components along with their brief descriptions are presented in Table 2.

3 QFD matrix

3.1 QFD matrix introduction

QFD was originated in 1966 at the Mitsubishi’s Kobe shipyard and has been used in both Japan and the United States [13]. QFD is a system for translating customer requirements into suitable technical characteristics and ensuring that important ones are prioritized in the design [14]. The house of quality (HoQ) is known as a basic methodology for QFD, which build a relationship between customer needs and quality characteristics. We used a QFD matrix based on the research of Arditi and Lee [1] for assessing the quality management performance of contractors. Fig. 1 shows elements of QFD matrix.

3.2 Implementing process

Step 1 Variable identification. Fig. 1 shows that the QFD matrix contains two critical variables, engineering quality factors and QMS factors, which were presented in Table 1 and Table 2 respectively.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection and measurement</td>
<td>A special staff is arranged to inspect and measure the construction activities in order to control deviation occurs.</td>
</tr>
<tr>
<td>Nonconforming product control</td>
<td>It must strictly identify and control nonconforming product and make management decisions correspondingly. Any product not meet the requirements can not be delivered.</td>
</tr>
<tr>
<td>Quality records and reports</td>
<td>There should be a quality record and report system to promptly and accurately note the quality management activities and periodically report to proper administration.</td>
</tr>
<tr>
<td>Training</td>
<td>Training must be targeted for every level of the company like managers, engineers, technicians, field office staff, support personnel and field labors.</td>
</tr>
<tr>
<td>Teamwork</td>
<td>Quality teams provide companies with the structured environment necessary for successfully implementing and continuously applying the quality management process.</td>
</tr>
<tr>
<td>Communication</td>
<td>Quality managers and staffs keep good communication and share information for measuring and improving quality performance.</td>
</tr>
<tr>
<td>Design control</td>
<td>Control measures should be formulated to make sure construction work is done strictly according to the drawings and specifications, and defects of design can be timely found.</td>
</tr>
<tr>
<td>Statistical control techniques</td>
<td>Statistical methods provide problem-solving tools to identify the causes of quality problems, communicate in a precise language, reproduce measures based on data, and make decisions on facts.</td>
</tr>
</tbody>
</table>
Fig. 1 Structure of quality function development matrix where $C_{Ri}$ is the customer requirement $i$ and $i = 1, 2, 3, ..., m$; $T_{Cj}$ is the technical characteristic $j$ and $j = 1, 2, 3, ..., n$; $W_i$ is the normalized importance weight of $i$; $H_j$ is the normalized importance weight of $j$; and $R_{ij}$ is the relationship between $i$ and $j$.

**Step 2** Data collection. The importance weights of customer requirement $W_i$ can be determined by interview and questionnaire to owners. The importance weights of technical characteristic $H_j$ can be decided by interview and questionnaire to contractors. The importance rating in Fig. 1 needs to be normalized and also add up to 1.

\[
\sum_{i=1}^{m} W_i = 1, \quad i = 1, 2, 3, ..., m; \tag{1}
\]

\[
\sum_{j=1}^{n} W_j = 1, \quad j = 1, 2, 3, ..., n. \tag{2}
\]

The strength of interrelationship matrix $I$ between customer requirements and technical characteristics, and auto-correlation matrix $P$ between technical characteristics should be determined by discussion of experts. To consider the impact of auto-correlation matrix $P$ between technical characteristics on interrelationship matrix $I$, the strength of interrelationship matrix $R$ should be modified by

\[
R = IP = \left| L_{ij} \right|_{mn \times mn} \cdot P_{jk} \left| W_{mr} \right|. \tag{3}
\]

**Step 3** Data processing. Data processing matrix is presented in Fig. 2. $P_{ii}$ represents the existing status of the customer requirements and $P_{jj}$ represents the existing status of the technical characteristics. They are evaluated and specified on a scale of 1 to 5, where 1 represents “poor” and 5 represents “excellent.”

**Step 4** Calculating actual performance level. The level of actual performance $L_{Ai}$ for each customer requirement can be obtained from the equation:

\[
L_{Ai} = \frac{\sum_{j=1}^{n} W_i \times P_{ij} + H_j \times P_{ij}}{2} \times R_{ij}, \quad 1 \leq i \leq m, \quad 1 \leq j \leq n. \tag{4}
\]

**Step 5** Calculating maximum performance level. The level of maximum performance $L_{Mi}$ is achieved if the existing status in all $P_{ii}$ and $P_{jj}$ are rated as “5 excellent”. The level of performance maximum $L_{Mi}$ for each customer requirement can be calculated by

\[
L_{Mi} = \frac{\sum_{j=1}^{n} W_i \times 5 + H_j \times 5}{2} \times R_{ij}, \quad 1 \leq i \leq m, \quad 1 \leq j \leq n. \tag{5}
\]

**Step 6** Calculating quality performance scores. The quality performance index $Q_{pi}$ for each customer requirement can be obtained from

\[
Q_{pi} = \frac{L_{Ai}}{L_{Mi}} \times 100\%. \tag{6}
\]

The total quality performance $Q_{pi}$ can be obtained by

\[
Q_{pi} = \sum_{i=1}^{m} \frac{L_{Ai}}{L_{Mi}} \times 100\%, \quad 1 \leq i \leq m. \tag{7}
\]

\[
\sum_{i=1}^{m} L_{Ai} \leq L_{Mi} \leq \sum_{i=1}^{m} L_{Ai}
\]
4 Research methodology

The methodology adopted in this study to develop a mathematical model for measuring the quality management performance of contractors is presented in Fig. 3.

Research may be quantitative or qualitative in nature. We adopted the quantitative positivist research in the form of survey study and statistical analysis. The general data collection techniques for quantitative research are secondary data sources, objective measures or tests, semi-structured interview questions and structured survey questionnaires. Semi-structured interviews and survey questionnaires were adopted which was specially designed for this study as data collection technique.

From the literature review, seven engineering quality factors (Table 1) and eight QMS factors (Table 2) were identified. The research method had the aim of investigating QMS factors (Table 2) that achieve the satisfaction level on engineering quality factors defined in Table 1.

According to QFD matrix method, the importance weights for customer requirements and technical characteristics and their relationship should be determined. So the interviews and questionnaire were conducted in three parts. The respondents have been involved as owner, contractors and research staff. Respondents were requested to be familiar with the engineering quality management. The questionnaire results were evaluated by using the most common statistical software SPSS 17.0 for Windows.

A survey questionnaire (marked as A) was administered to all 60 construction owners. We received 51 completed responses and 9 invalid responses with a response rate of 70\%\). Because the contractors provide construction products for the owners, so the owners can be considered as the customers of contractors. The relative importance of engineering quality factors was sought for using in QFD calculations. Questionnaire A is based on existing
Likert measurement scales that respondents were asked to rate engineering quality factors on a five-point scale anchored by “very important” to “very unimportant”. The values assigned by owners were later normalized in the date processing matrix.

A survey questionnaire (marked as B) was administered to all 60 contractors. We received 49 completed responses and 8 invalid responses with a response rate of 68.33%. The relative importance of QMS factors was sought for using in QFD calculations. Questionnaire B is also based on existing Likert measurement scales and the values assigned by contractors were later normalized.

This paper was supported by a research program sponsored by Ministry of Housing and Urban-Rural Development of the People’s Republic of China. A research team for this program consists of professors, doctoral students, master students, government officials and some staffs came from enterprise. Delphi method was used to analyze the relationship between engineering quality factors and QMS factors. Usually, 0 to 9 scales (Table 3) were used to describe the relationship between two kinds of factors [15]. Relationship scores were finally obtained by many discussions between experts invited by research group. The values in the relationship matrix were later normalized in the date processing matrix.

### Table 3  A 0 to 9 scales of relationship

<table>
<thead>
<tr>
<th>Scale</th>
<th>Relationship</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No relationship</td>
</tr>
<tr>
<td>1</td>
<td>Very weak relationship</td>
</tr>
<tr>
<td>3</td>
<td>Weak relationship</td>
</tr>
<tr>
<td>5</td>
<td>Average relationship</td>
</tr>
<tr>
<td>7</td>
<td>Strong relationship</td>
</tr>
<tr>
<td>9</td>
<td>Very strong relationship</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Between adjacent scales</td>
</tr>
</tbody>
</table>

### 5 A case study

#### 5.1 Data processing and formation of QFD matrix

Cronbach $\alpha$ was used in reliability analysis for questionnaire A and questionnaire B. The Cronbach $\alpha$ were 0.563 and 0.760 respectively (Table 4). Questionnaires are reliable and can be used for following analysis.

<table>
<thead>
<tr>
<th></th>
<th>Questionnaire A</th>
<th>Questionnaire B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valid</td>
<td>42</td>
<td>41</td>
</tr>
<tr>
<td>Excluded</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>41</td>
</tr>
<tr>
<td>Cronbach $\alpha$</td>
<td>0.563</td>
<td>0.760</td>
</tr>
</tbody>
</table>

Each factor has its different influence, which can be reflected by importance weights index. The mean value of Delphi questionnaire A was used to calculate the importance weights for every engineering quality factor according to Eq. (8).

$$W_i = \frac{M_i}{m}, \quad i = 1, 2, 3, ..., 7,$$

$$\sum_{i=1}^{m} M_i$$

where $W_i$ is the importance weights of factor $i$ and $M_i$ is the mean value of factor $i$.

Eq. (8) must match any of the following:

$$W_i \in [0,1], \quad W_1 + W_2 + W_3 + \cdots + W_7 = 1.$$

The mean value of Delphi questionnaire B was used to calculate the importance weights for every QMS factor according to Eq. (9).

$$H = (H_1, H_2, H_3, H_4, H_5, H_6, H_7, H_8),$$

$$H_j = \frac{M_j}{m}, \quad j = 1, 2, 3, ..., 8.$$

where $H_j$ is the importance weights of factor $j$ and $M_j$ is the mean value of factor $j$.

Eq. (9) must match any of the following:

$$H_1 \in [0,1], \quad H_1 + H_2 + H_3 + \cdots + H_8 = 1.$$

The mean, weights and rank of all the factors for engineering quality factors and QMS factors are presented in Table 5. Relationship matrix $I$ between engineering quality factors and QMS factors was given by experts on 0 to 9 scales. Then the value must be normalized according to
the principle “Normalized value = (Actual value-0)/(9-0)” and be described as

\[
I = \begin{bmatrix}
9 & 9 & 7 & 5 & 4 & 4 & 3 & 2 \\
8 & 8 & 7 & 5 & 4 & 4 & 6 & 2 \\
6 & 6 & 6 & 4 & 4 & 4 & 8 & 2 \\
4 & 5 & 4 & 3 & 3 & 3 & 6 & 6 \\
6 & 6 & 5 & 4 & 4 & 4 & 8 & 2 \\
5 & 6 & 5 & 4 & 4 & 6 & 5 & 2 \\
3 & 3 & 3 & 3 & 2 & 2 & 2 & 2
\end{bmatrix}
\begin{bmatrix}
1.000 \\
0.889 \\
0.667 \\
0.444 \\
0.667 \\
0.556 \\
0.333 \\
0.222
\end{bmatrix}
\begin{bmatrix}
1.000 \\
0.778 \\
0.556 \\
0.444 \\
0.667 \\
0.556 \\
0.333 \\
0.222
\end{bmatrix}
\begin{bmatrix}
0.444 \\
0.556 \\
0.667 \\
0.444 \\
0.667 \\
0.556 \\
0.333 \\
0.222
\end{bmatrix}
\begin{bmatrix}
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444
\end{bmatrix}
\begin{bmatrix}
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333
\end{bmatrix}
\begin{bmatrix}
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222
\end{bmatrix}
\]

Auto-correlation matrix \( P \) between engineering quality factors was also given by experts on 0 to 9 scales. The value also should be normalized according to the same principle and be described as

\[
P = \begin{bmatrix}
9 \\
5 & 9 \\
5 & 3 & 9 \\
0 & 0 & 0 & 9 \\
0 & 0 & 0 & 0 & 9 \\
0 & 0 & 0 & 0 & 5 & 9 \\
0 & 0 & 3 & 0 & 0 & 0 & 9 \\
1 & 1 & 1 & 0 & 0 & 0 & 0 & 9
\end{bmatrix}
\begin{bmatrix}
1.000 \\
0.556 \\
0.556 \\
0.000 \\
0.000 \\
0.000 \\
0.000 \\
0.111
\end{bmatrix}
\begin{bmatrix}
1.000 \\
0.778 \\
0.556 \\
0.444 \\
0.667 \\
0.556 \\
0.333 \\
0.222
\end{bmatrix}
\begin{bmatrix}
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444 \\
0.444
\end{bmatrix}
\begin{bmatrix}
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333 \\
0.333
\end{bmatrix}
\begin{bmatrix}
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222 \\
0.222
\end{bmatrix}
\]

Table 5  Importance weights for variables

<table>
<thead>
<tr>
<th>Item</th>
<th>Mean</th>
<th>Variance</th>
<th>Weights</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering quality factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structural integrity</td>
<td>4.95</td>
<td>0.309</td>
<td>0.170</td>
<td>1</td>
</tr>
<tr>
<td>Functional adequacy</td>
<td>4.38</td>
<td>0.764</td>
<td>0.151</td>
<td>2</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>3.93</td>
<td>0.745</td>
<td>0.135</td>
<td>6</td>
</tr>
<tr>
<td>Economic</td>
<td>4.00</td>
<td>0.826</td>
<td>0.138</td>
<td>4</td>
</tr>
<tr>
<td>Conformance</td>
<td>3.48</td>
<td>1.110</td>
<td>0.120</td>
<td>7</td>
</tr>
<tr>
<td>Customer satisfaction</td>
<td>4.31</td>
<td>0.749</td>
<td>0.148</td>
<td>3</td>
</tr>
<tr>
<td>Ecologic quality</td>
<td>4.00</td>
<td>0.826</td>
<td>0.138</td>
<td>5</td>
</tr>
<tr>
<td>QMS factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inspection and measurement</td>
<td>4.71</td>
<td>0.559</td>
<td>0.144</td>
<td>1</td>
</tr>
<tr>
<td>Nonconforming product control</td>
<td>4.51</td>
<td>0.925</td>
<td>0.138</td>
<td>2</td>
</tr>
<tr>
<td>Quality records and reports</td>
<td>4.24</td>
<td>0.767</td>
<td>0.129</td>
<td>3</td>
</tr>
<tr>
<td>Training</td>
<td>3.56</td>
<td>0.776</td>
<td>0.108</td>
<td>8</td>
</tr>
<tr>
<td>Teamwork</td>
<td>4.15</td>
<td>0.792</td>
<td>0.126</td>
<td>4</td>
</tr>
<tr>
<td>Communication</td>
<td>3.90</td>
<td>0.944</td>
<td>0.119</td>
<td>6</td>
</tr>
<tr>
<td>Design control</td>
<td>4.10</td>
<td>0.860</td>
<td>0.125</td>
<td>5</td>
</tr>
<tr>
<td>Statistical control techniques</td>
<td>3.63</td>
<td>1.043</td>
<td>0.111</td>
<td>7</td>
</tr>
</tbody>
</table>
Modification interrelationship matrix $R$ should be modified by Eq. (3) and

$$
R = IP = \begin{bmatrix}
2.013 & 1.840 & 1.470 & 0.556 & 0.691 & 0.691 & 0.592 & 0.530 \\
1.840 & 1.667 & 1.519 & 0.556 & 0.691 & 0.691 & 0.926 & 0.506 \\
1.433 & 1.285 & 1.359 & 0.556 & 0.691 & 0.691 & 1.111 & 0.444 \\
1.074 & 1.025 & 0.987 & 0.333 & 0.518 & 0.518 & 0.815 & 0.827 \\
1.372 & 1.248 & 1.248 & 0.444 & 0.691 & 0.691 & 1.074 & 0.432 \\
1.261 & 1.186 & 1.075 & 0.444 & 0.815 & 0.914 & 0.741 & 0.419 \\
0.728 & 0.654 & 0.617 & 0.333 & 0.345 & 0.345 & 0.333 & 0.333 \\
\end{bmatrix}
$$

5.2 Formation of QFD matrix

The data collected through the three surveys administered to construction owners, contractors and research staffs are converted in QFD matrix (Fig 4).

5.3 Case calculation

Taking a commercial building project constructed by contractor H as an example, a case study was carried on to test the QFD matrix model.

Construction owners were invited to assess the building project’s quality. Fig 5 shows present status for engineering quality factors given by owner and present status for QMS factors given by contractors. The level of actual performance were calculated by Eq. (4). Assuming that the maximum achievable performance status in each factor is a perfect $5$, the level of maximum performance expected for the commercial building project were calculated as Eq. (5).

The level of quality performance of each customer requirement in this case is calculated by Eq. (6) (Fig. 5). As illustrated in Fig. 5, the performance of structural integrity, functional adequacy, conformance, and ecologic quality are better than others.

<table>
<thead>
<tr>
<th>Quality management system</th>
<th>Inspection and measurement</th>
<th>Nonconforming product control</th>
<th>Quality records and reports</th>
<th>Training</th>
<th>Teamwork</th>
<th>Communication</th>
<th>Design control</th>
<th>Statistical control techniques</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering quality</td>
<td>Weight</td>
<td>0.144</td>
<td>0.138</td>
<td>0.129</td>
<td>0.108</td>
<td>0.126</td>
<td>0.119</td>
<td>0.125</td>
</tr>
<tr>
<td>Structural integrity</td>
<td>0.170</td>
<td>2.013</td>
<td>1.840</td>
<td>1.470</td>
<td>0.556</td>
<td>0.691</td>
<td>0.691</td>
<td>0.592</td>
</tr>
<tr>
<td>Functional adequacy</td>
<td>0.151</td>
<td>1.840</td>
<td>1.667</td>
<td>1.519</td>
<td>0.556</td>
<td>0.691</td>
<td>0.691</td>
<td>0.926</td>
</tr>
<tr>
<td>Aesthetics</td>
<td>0.135</td>
<td>1.433</td>
<td>1.285</td>
<td>1.359</td>
<td>0.556</td>
<td>0.691</td>
<td>0.691</td>
<td>0.691</td>
</tr>
<tr>
<td>Economic</td>
<td>0.138</td>
<td>1.074</td>
<td>1.025</td>
<td>0.987</td>
<td>0.333</td>
<td>0.518</td>
<td>0.518</td>
<td>0.518</td>
</tr>
<tr>
<td>Conformance</td>
<td>0.120</td>
<td>1.372</td>
<td>1.248</td>
<td>1.248</td>
<td>0.444</td>
<td>0.691</td>
<td>0.691</td>
<td>1.074</td>
</tr>
<tr>
<td>Customer satisfaction</td>
<td>0.148</td>
<td>1.261</td>
<td>1.186</td>
<td>1.075</td>
<td>0.444</td>
<td>0.815</td>
<td>0.914</td>
<td>0.741</td>
</tr>
<tr>
<td>Ecologic quality</td>
<td>0.138</td>
<td>0.728</td>
<td>0.654</td>
<td>0.617</td>
<td>0.333</td>
<td>0.345</td>
<td>0.345</td>
<td>0.333</td>
</tr>
</tbody>
</table>

Fig. 4 Quality function development matrix
The $Q_{pi}$ of the building in this example, which is the last step in processing procedure, is obtained according to Eq. (7).

$$Q_{pi} = \frac{\sum_{i=1}^{7} L_{Ai}}{\sum_{i=1}^{7} L_{Mi}} \times 100\% = \frac{5.964 + 5.556 + 4.163 + 3.338 + 6.301 + 5.900 + 4.054 + 4.175 + 3.931 + 2.113}{4.485 + 4.742 + 2.257} \times 100\% = 89.3\%$$

The result of 89.3% is close to 100%. Therefore, the quality management of contractor H for this commercial building project is effective.

6 Conclusions

It is determined that some of the construction firms are operating QMS but they have no way of measuring the effectiveness of these systems. The proposed quality performance method using QFD matrix can effectively measure the quality management performance of an individual contractor to their projects. The $Q_{pi}$ index can quantitatively reflect the level of quality management efficiency and effect, which can be taken as an assessing tool not only for contractors but also for owners. The $Q_{pi}$ is valuable for individual contractors who can use it to compare their performance in different projects and take measures to maximize their performance index in future projects. It can be used to conduct self-diagnosis, improvement, motivation, and training for achieving higher corporate quality standards and benchmark themselves against their competitors. The $Q_{pi}$ is also valuable for owners who can use it to accurately evaluate the quality performance level for the projects and judge the quality management ability of contractors that can be invaluable in the process of deciding which contractor to pick for a particular project.

However, there also exist any defects. There is no clear standard for $Q_{pi}$ to judge what is excellent. Additionally, the importance weights and relationship scores were determined by questionnaire and interview, so the inaccuracy of date will arise due to experts’ subjectivity. The components of QMS and...
measurement method of quality performance may well be developed. Future research should include the improvement of definition of variables and development of measure tools.

To improve quality effectiveness in construction firms, it is an appropriate way to encourage contractors to set up an effective quality performance measure system under the full support of government such as Reward of Achievement Programs, Scoring, and Performance Assessment Systems implemented in Singapore and Hong Kong.

References


Edited by XUE Jing-yuan