エンジニアリング・エコノミクスのための建設プロジェクトの品質評価に関する研究

Measuring Quality of Construction Projects for Engineering Economic Analysis

Bui Trong Cau* – Ph.D. Candidate, The University of Tokyo
Masahiko Kunishima** – Prof., The University of Tokyo
Tsuneaki Yoshida** – Prof., The University of Tokyo
Tomonari Yashiro** – A. Prof., The University of Tokyo

Abstract

This paper introduces a concept of measuring quality for engineering economic analysis to determine the best quality for construction projects. First, the quality of construction projects is defined and decomposed into component quality criteria. Next, the component quality criteria are quantified and the weights of relative importance level of each component quality criterion are determined. In this way, the value of the entire quality of construction projects can be consequently measured. Having measured the quality value, the engineering economic analysis can be applied and the optimum quality of construction projects will be determined by incremental quality value- costs ratio analysis accordingly.

Keywords: Component Quality, Fuzzy Characteristics, Index of Importance Level, Quality Value, Acceptable Threshold of Quality Value/Costs Ratio

1. Introduction

Quality and costs are the most concerned attributes in investing in any construction project. In general, to invest in a construction project that intends to meet market demands or needs, conceptual plans and feasibility studies must necessarily be carried out first of all. Various possibilities are considered in the

*工学系研究科社会基盤工学専攻
Tel: 03-3812-2111 ext. 6143
**工学系研究科社会基盤工学専攻

conceptual planing stage; and technological and economical feasibility of each alternative which is expressed in attributes of project such as serviceability, service life, durability, safety, appearance and so on will be assessed and compared to select the best alternative with due condition of a certain limitation of available budget. The appraisal of quality alternatives to select the best quality alternative at the stage of feasibility studies plays a very important role since this stage greatly influences the output quality of investments. However, the economic appraisal methods that are being used do not necessarily give the best result because there are many attributes involved in construction projects which are not measured in monetary terms such as serviceability, reliability, appearance and so on. These attributes can not totally be included in the economic analyses. Therefore this paper intends to propose a concept to develop a new method to measure quality of construction projects for engineering economic analysis in order to select the optimum alternative which meets the societies' best satisfaction.

2. Definition of the Quality of Construction Projects

There are dozens of definitions of quality. In general, there are two widely accepted definitions.

Definition 1: Quality is satisfaction of customers

Definition 2: Quality is fitness for use

In construction, ***the ISO Standard 8402: Quality: Vocabulary*** defines quality of construction projects as the totality of characteristics of a construction work that bear on its ability to satisfy stated or implied needs.

Concretizing the definition of the ISO Standard 8402, the quality of construction projects can be expounded as a complex criterion that includes nine following aspects:

. Serviceability of project for use purpose
. Benefits of project including economic benefit and social benefit
. Durability of project
. Safety degree and working environment in construction and operation
. Reliability of project in operation
. Appearance of project
. Aesthetic and culture values of project
. Environment friendliness of project
. Construction duration of project.

Construction product (project) has a particular feature in comparison with other industry products such as cars and computer; and therefore quality attributes of construction project have a corresponding particular characteristics compared to quality attributes of industrial products. In case of industrial products, customers select a satisfied product among available similar products on the market and purchase for the selected product. All the industrial products on the market have always been made by manufacturers; and customers are never and do not have to be interested in manufacturing process of the products. In construction, on the contrary, the clients (owners) have to purchase for and are concerned to all activities from the initial stages of product manufacture (researching market demand or perceived needs, making conceptual planning & feasibility studies, designing, constructing) until the last stage of product demolition (removal of project). Therefore, in construction the owners must be interested in not only characteristics of product itself as in industry but also in characteristics of product manufacturing process such as safety degree and working environment in construction as well as construction duration.

3. Characteristics of Quality of Construction Project from the Viewpoint of Measurement

From the above mentioned aspects of quality of construction projects, we can draw some important characteristics associated with the quality of construction projects from the viewpoint of quality measurement:

(1) Each aspect of the quality of construction projects may contain many sub-aspects and vary from project to project. For example, the aspect of serviceability may contain many sub-aspects such as comfortable level, ability of sound proof in case of a theatre; and the serviceability of a theatre is different from that of a highway.

(2) Some aspects such as appearance or aesthetic and culture values of construction projects can not be measured by normal methods since they depend on feeling and subjective judgement of evaluators. In other words, they are fuzzy in perception.

(3) Aspects of quality of construction projects are very different each other in characteristics, meanings and measurement units. Moreover, the relative importance levels of aspects are also different one another and depend on concrete circumstances. In other words, they are also fuzzy in measuring. This means that even if we can measure all aspects of the quality, we are still unable to sum up them accordingly.

(4) On the one hand, quality is a "relative" concept in the sense that one cannot actually measure the "quality of project A", but rather, the "quality of project A relative to project B". On the other hand, one could also

consider an "absolute quality change" when the quality of the same project is compared in different places (such as in different countries or areas) or in different times.

The characteristics of quality of construction projects identified are very significant in making right strategy to measure quality of construction projects.

4. Measurement of the Quality for Construction Projects

From the characteristics of quality of construction projects identified, we can realize that measuring the quality of construction projects must fulfill the following requirements:

(1) Full reflection of quantity of the quality aspects for each alternative
(2) Full reflection of levels of importance of the quality aspects
(3) Reflection of quality of alternatives in the sense that quality of each alternative is measured in relation to those of the others in certain circumstances.

Thus, a method to measure the quality of construction projects at the stage of feasibility study may comprise the following five steps:

(1)Decompose the overall quality of project into concrete component quality criteria.
(2)Determine component quality criteria of each alternative
(3)Determine the relative importance level of each criterion with respect to the others.
(4) Redefine quantity of component quality criteria of each alternative in relative consideration to those of the other alternatives
(5)Determine the value of quality for each alternative by integrating the determined importance levels and the redefined quantities.

(1) ***<u>Step 1</u>*: Decompose the overall quality into concrete component criteria.**

Certainly, the component quality criteria greatly vary from project to project. It is important to emphasize that the component quality criteria decomposed must be identical enough to be independently quantified or measured and they must not overlap one another. Some example component quality criteria of a highway project are listed below:

. Traffic flowing ability
. Allowable maximum safety speed
. Comfortable level to users
. Service life of project
. Economic efficiency in use
. Durability of project

. Ability of earthquake resistance
. Safety degree in construction process
. Safety degree in operation process
. Costs for operation, maintenance and repair.
. Social benefit of project and others

(2) ***Step 2:*** **Quantify component quality criteria for each alternative**

Quantifying the component quality criteria for each alternative largely depends on construction technology applied and various conditions of project. Conventionally, the component quality criteria can be classified into three groups in accordance with available methods to determine criteria:

. Group 1: "Formalized Criteria" such as economic efficiency in use, ability of leak proof, ability of sound proof. Methods to quantify these criteria have been well known and accepted in practice.

. Group 2: "Semi-formalized Criteria" such as serviceability of project, durability of project, degree of environmental protection and improvement. Methods to quantify these criteria depend on various conditions of project and mainly rely on statistical data, experiences of built similar projects or test results in laboratories.

. Group 3: Fuzzy Criteria such as aesthetic and culture values, beauty of project. Quantification of the fuzzy criteria may be possible by applying the Delphi Technique that will be explained in the next section.

Now, let us define m component quality criteria by q1, q2,... qj...qm. Assuming that there are n project quality alternatives, thus we can define a matrix of the component quality criteria q as follows:

$$q = \begin{Vmatrix} q11 & q12 & \dots & q1m \\ q21 & q22 & \dots & q2m \\ \dots & \dots & qij & \dots \\ qn1 & qn2 & \dots & qnm \end{Vmatrix}$$

(3) ***Step 3:*** **Determine the importance level of each criterion with respect to the others.**

Basically, the relative importance levels of the component quality criteria are determined by aggregating judgments of each component criterion with respect to the others. This aggregations of judgments can be possible by application of the principle of hierarchy structure approach and the principle of pair-wise comparison.

To make the pair-wise comparison, a ratio scale must be established first. Then, the aggregation of judgments concerns generating weights for each of the criteria by pair-wise comparison. This involves a subjective assignment of relative important level to each criterion. Let value Ihk be assigned by comparing criterion qh to qk. Thus the resulting factor Ihk is the relative important level of qh compared to qk. We have a matrix I, which reflects the important level preference of the pair-wise comparison, as follows:

$$I = \begin{Vmatrix} I11 & I12 & \ldots & I1m \\ I21 & I22 & \ldots & I2m \\ \ldots & \ldots & Ihk & \ldots \\ \mathrm{Im}1 & \mathrm{Im}2 & \ldots & \mathrm{Im}\,m \end{Vmatrix}$$

There is an important question that is how to estimate values Ihk? We propose to employ the Delphi Technique to estimate values Ihk as well as to quantify Fuzzy Criteria.

The Delphi Technique was originally developed by the Rand Corporation of USA in 1948 to forecast the Russia Military Air Strategy. Basically, the typical process of the Delphi Technique is described as follows:

(a) A panel of experts on the issue is selected from both inside and outside the organization.

(b) The experts are asked (anonymously so that they will not be influenced by others) to make their estimate or forecast on the issue

(c) The answers are compiled, and the composite results are fed back to the panel members.

(d) With this information at hand (but still with individual anonymity), further estimate are made

(e) This process may be repeated several times

(f) When a convergence of opinion begins to evolve – Stop.

Note that there is no pressure to arrive at a consensus. The Delphi Method does not necessarily give certain final results but may only provide useful information to make the final results.

In application of the Delphi Method to quantify Fuzzy Criteria and estimate values Ihk, a ratio scale must be first set up for the quantification and estimation as mentioned above. Because the different ranges of both the fuzzy criteria and the importance levels of criteria (Ihk) may be very large, we suggest a ratio scale of 100 points for the quantification and estimation. The results obtained by the method can be used in three ways depending on particular issues and concrete situations to reach the final result:

(a) Accept the consented result, if any, as the final result
(b) Favor the weighted average value of the obtained result
(c) Consider the obtained result as reference information to make the final decision.

Having determined matrix I, a weight vector W pertaining to the component quality criteria can be determined by calculating the eigen-vector corresponding to the maximum eigen-value of the matrix. This vector indicates the set of weights for each component quality criterion reflecting its relative importance to the others.

$$W= \{ w1,w2, ...wj...wm\}$$

(4) ***Step 4:*** **Redefine the quantified component quality criteria of each alternative in relative consideration to those of the other alternatives**

As mentioned above, because aspects of quality of construction projects are very different each other in characteristics, meanings and measurement unit, we can not sum up them simply. On the other hand, quality is a "relative" concept in the sense that one cannot actually measure the "quality of project A", but rather, the "quality of project A relative to project B" or "a quality of an alternative relative to those of other alternatives for the same project". Thus, the following technique are introduced to redefine the quantified component quality criteria to reflect the quality criteria of each alternative in relative consideration with those of the other alternatives.

a) Making Criteria be the same direction.

The component quality criteria are classified into two groups. The first group includes criteria, which can be explained by statement: "their quality will increase if their quantity increases". Examples of these criteria are service life of project, duration of project, safety degree of project and so on. The second group includes the other criteria, which can be explained by statement: "their quality will increase if their quantity decreases". Examples of these criteria are construction costs, damages from construction and construction duration of project and so on. It is required to make criteria to be the same direction or the same group i.e. they all will be either "their quality will increase if their quantity increases"; or "their quality will increase if their quantity decreases". If the direction "their quality will increase if their quantity increase" is selected, the criteria of "their quality will increase if their quantity decreases" will be made to be their inverse figures so that they become "their quality will increase if their quantity increases " .

b) Redefine the quantified component quality criteria of each alternative in relative consideration to those of the other alternatives

Having made all component quality criteria to be the same direction, we redefine them by following formula to reflect the quality criteria of each alternative in relative consideration with those of the other alternatives :

$$q*ij = \frac{qij}{\sum_{i=1}^{n} qij} \times 100$$

Step 5: **Determine the quality value for each alternative**

Having estimated q*ij and wj, we can determine the quality value for each alternative i by the following formula:

$$Vi = \sum_{j=1}^{m} q*ij \times wj$$

. q*ij: Redefined quantity of component quality criterion j of alternative i
. wj: Weights for importance level of component quality criterion j

So, one may say that the quality of construction projects is measured by "the quality value" that reflects the quality *in non-measurement unit.*

5. Appraise Quality Alternatives by Incremental Quality Value – Costs Ratio Analysis.

Let us denote the quality value and costs of construction projects by V and C respectively. The appraisal of quality alternatives can be made by the principle of incremental quality value -costs ratio analysis as follows:

(1) Step 1: Determine acceptable threshold of quality value/costs ratio

Let us denote the acceptable threshold of quality value/costs ratio by [V/C]. Certainly, [V/C] is not necessarily 1

(2) Step 2: Determine quality value and costs of alternatives (Vi and Ci); and determine ratio Vi/Ci i=1,n

(3) Step 3: Eliminate non-worthwhile alternatives.

Let's compare Vi/Ci with [V/C]. Unacceptable alternatives u are the alternatives that have Vu/Cu < [V/C].

(4) Step 4: Appraise worthwhile alternatives to select the optimum.

a) *Determine Incremental Quality Value – Costs Ratios*

$$\frac{\Delta V}{\Delta C}$$

b) *If there are two worthwhile alternatives and if*

$$\frac{\Delta V}{\Delta C} \geq [V/C]$$

then choose the higher cost alternative. Otherwise, choose the lower cost alternative.

c) *If there are three or more worthwhile alternatives*:

Repeatedly appraise for two alternatives, choose the better and then continuously appraise for the chosen alternative and a subsequent alternative and so on. The final result of this series appraisal shall be the overall best selection.

***(5) Step 5:* Sensitivity Analysis**

Sensitivity analysis is necessary for many cases to make the final decision. Since many data gathered in solving a problem represent projections of future consequences, there may be considerable uncertainty regarding the accuracy of the data used. As the desired result of the analysis is decision making, an appropriate question is "to what extent to variations in the data affect our decision". When small variations in a particular estimate would change selection of the alternative, the decision is said to be sensitive to the estimate. To better evaluate the impact of any particular estimate, we compute " what variation to a particular estimate would be necessary to change a particular decision".
Moreover, when there are

$$\frac{\Delta V}{\Delta C} < [V/C]$$

but they are very approximate to [V/C], the sensitivity analysis is also necessary to be done.

6. Concluding Remarks

This paper has presented the concept of measuring the quality of construction projects for facilitating engineering economic analysis of quality for construction projects .

To make the concept to be an applicable method, the further studies listed below are essential:

1) The measurement of relative importance level of the component quality criteria are based on assumption that the component quality criteria are independent one another. Therefore, how to decompose the quality into component quality criteria so that they become

relatively independent one another is very important.

2) The proposed incremental quality value -costs ratio analysis for construction projects presented here is only limited to the case that capabilities (or scale) of alternatives are the same. In the other case, the problem will become much complicated.

3) The determination of the acceptable thresholds of ratio V/C ([V/C]) for the appraisal is also a pending issue.

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