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Utility Model for Evaluation of Alternative Procurement Methods

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Abstract

A major decision the owner of a facility project has to make during the planning phase is selection of a procurement method, as it will have a significant influence on the management and performance of the project. In addition to the traditional design-bid-build method, there are alternatives routes such as design/build and management contracting that may be selected. These methods have different strengths and weaknesses, and the selection must consider the nature of each method against the conditions of a project and the priorities of the owner, and the best method can only be found using an overall evaluation. Researches on applying decision analysis techniques to procurement method selection can be found in the literature, but they do not provide a quantitative analysis of project attributes, especially assessment of trade-offs between time and cost. This paper presents a multiple-criteria utility model for evaluating alternative procurement methods for a project according to estimated performance. The project duration and cost through each procurement route are estimated probabilistically and translated into utility values by utility functions. The utilities of other aspects including design quality and management of construction are also assessed. The weights of the criteria are determined using the analytical hierarchy process. The weighted total utility represents the overall evaluation of a procurement method. Case study involving a high schedule risk project of high complexity is presented to illustrate the proposed model. The results show that the model is sensitive enough to differentiate the effects of the system and organization of each procurement method in accordance with empirical expectations. Therefore, the model can serve as a decision aid for consistent evaluation of procurement methods.

Keywords

Procurement methods, Quantitative analysis, Utility theory

1. Introduction

In addition to investigating demand and feasibility, the owner of a facility project needs to make a major decision at the beginning phase that is selection of a procurement method or procurement route for project implementation. Because the method selected will affect the definition of project organization, i.e. the participants' roles and responsibilities, as well as the management and administration of contracts, the decision ultimately has an impact on project performance in time, cost, and quality. Besides the traditional method of separate procurement of design and construction services, alternative procurement routes such as design and build (D/B) and management contracting have become increasingly widespread. The present research intends to study evaluation of various procurement methods for completing a high schedule risk project. The high schedule risk may come from a tight time frame for project design and construction caused by the urgency of the owner's operation. It may also be due to the nature of work with highly sensitive productivity that causes high variability in project duration, such as earthwork and tunneling, as well as the uncertainties in design time for a complex project, such as the owner's frequent request for changes and delays in approval of designs submitted.

The premise of this research is that the owner will prefer to select the traditional method of separate procurement of design and construction services for a common project when there is no urgent need for speedy completion and other priorities, because it is the route that most people are familiar with. However, when facing a high schedule risk project, the owner would seriously consider alternative procurement methods such as design/build and management contracting. Although these alternatives each have the advantage of shortened completion time as a result of overlapping design and construction, they also have disadvantages. For example, because of the design/build method's feature of single point responsibility, the D/B contractor is exposed to greater risks inclusive of design, which presumably will be reflected by a higher bid price. Although the management contracting method can speed up construction and can better accommodate design changes, its cost certainty is lower. While the traditional method requires longer time, its performance in other aspects is good enough to serve as a benchmark for the alternative methods. Therefore, the selection must consider the nature of each method against the conditions of a project and the priorities of the owner, and the best method can only be found using an overall evaluation.

2. Research Objective

Because of the importance of the selection of a procurement method, formal decision analysis techniques and models are suitable for evaluating the alternative methods. The problem of selecting a procurement method for a project with high schedule risk presents a case of decision analysis under uncertainty where an option's utility is a function of risk. The objective of this research is to develop a quantitative model based on risk analysis and centered on the assessment of trade-offs between time and cost for evaluating alternative procurement methods. Because the evaluation involves also qualitative factors in design and management, it is proposed to investigate using the multi-attribute utility theory for developing the model. The model will be illustrated using an example project.

3. Literature Review

In the literature there are many publications on researches in developing multi-attribute decision models for procurement method evaluation. Love et al (1998), based on the utility theory, proposed to pre-assign a utility score to each aspect of a procurement method, such as speed and cost certainty, according to experts' opinions and then assign a percentage weight to each aspect according to the owner's project priorities in order to produce a weighted total utility score for each alternative as the basis for selection. Likewise, Cheung et al (2001) gave utility scores of each procurement method on several criteria for the conditions of Hong Kong and proposed to use the analytical hierarchy process for obtaining the weights for the criteria for producing the total score for a method. However, they did not provide a quantitative assessment of project attributes, especially on the trade-offs between time and cost.

Konchar et al (1998) collected data on hundreds of completed projects in the US and produced statistics of performance for comparing procurement methods. However, an earlier research by Ward et al (1991) already pointed out that because of the uniqueness of a project its performance is influenced by numerous factors in project conditions and environments and hence any conclusions about a procurement method's performance based on statistics involving only a few factors can be challenged. Although differences in contractual arrangement between procurement methods certainly has an influence on project performance, the correlations between performance indicators and a number of other independent variables on project conditions, owner, and contractor also need to be established. However, such a multiple regression model would require a large number of project cases in order to obtain statistically significant results. Again, because of project uniqueness, the number of independent variables must be large enough to differentiate a project, which makes it difficult to determine an equation with the minimum set of variables.

4. Description of Model

As opposed to the above empirical approaches that are based on experts' opinions or statistics, the present research proposes an analytical model for evaluation of alternative procurement methods that is based on probabilistic cost and schedule estimates for each method as well as the utility theory. The process of the proposed model is shown in Figure 1. To obtain an overall evaluation of alternative procurement methods, the performance of each method in time, cost, and quality for completing a project is to be estimated for comparison. Because the selection decision is made at the early stage of a project without detailed project information, estimates of time and cost can only be made based on the owner's briefing for project definition and historical data on similar projects. The required main activities through each procurement route as well as project components and their estimated quantities of work are listed, becoming the basis for time and cost evaluation. Since there still exist a lot of uncertainties in the scope and project details, probabilistic or range estimates of time and cost are used, whereby incorporating the associated risks.

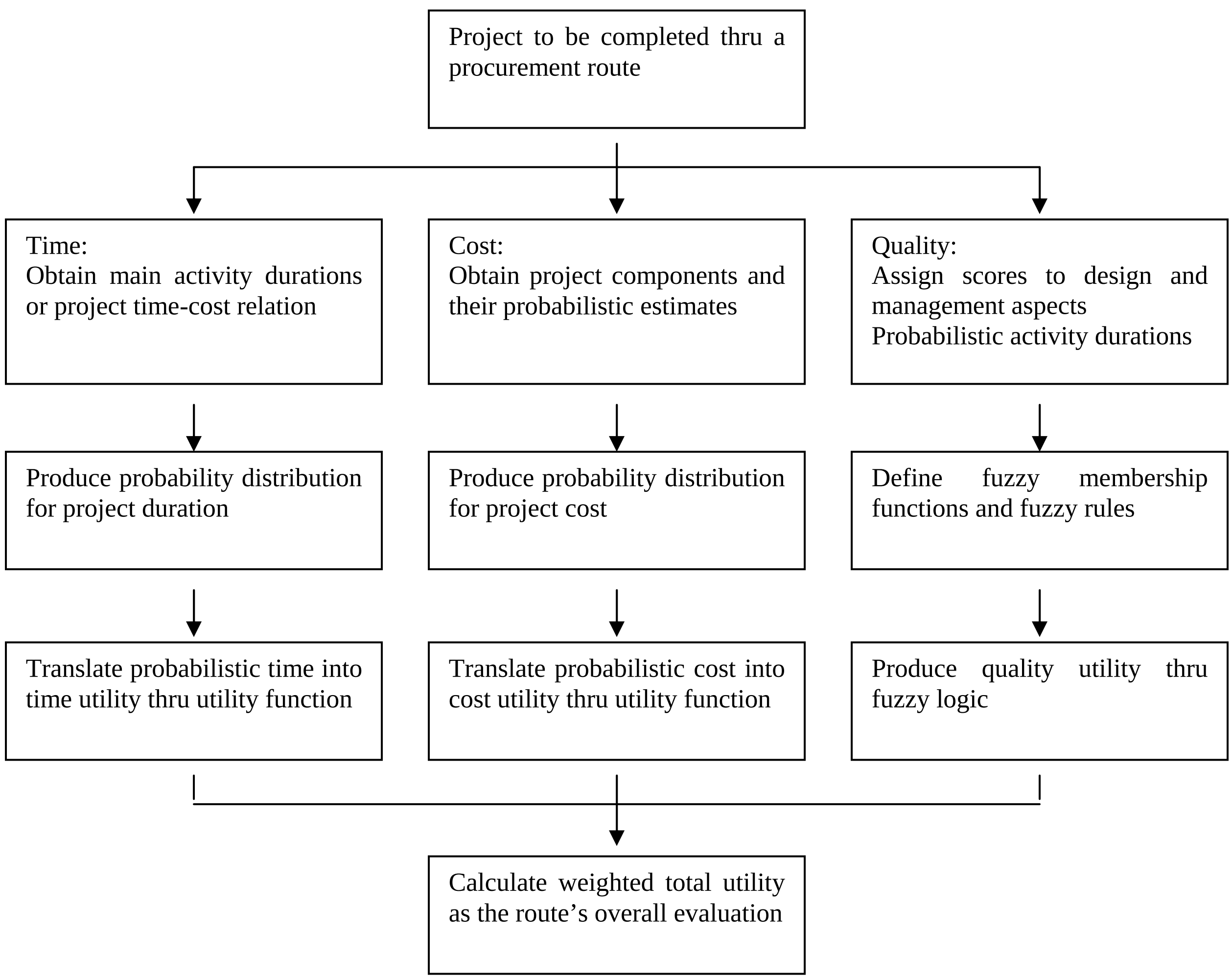

Figure 1: Process of the Model for Evaluation of Procurement Methods

For each procurement route, the required main activities and precedence relationships among them are determined according to the nature of the route, as reflected by a logic diagram (see Figure 2). Then, using estimated ranges of activity times for project conditions and typical practices, a probability distribution for project duration can be aggregated. Alternatively, a probabilistic estimate of project duration can be obtained using the probabilistic estimate of project cost and based on a statistical time-cost relation derived from similar past projects. The estimate for the traditional procurement route can be made first and then modified for obtaining the estimates for the alternative routes. The costs of project components will be estimated based on the estimated quantities of work and ranges of unit prices from historical data. An estimated probability distribution for project cost can then be obtained by aggregating the costs of the components using simulation or statistical theorems. Adjustments to the estimate for the traditional route are made to account for changes in project organization for estimating for the alternative routes.

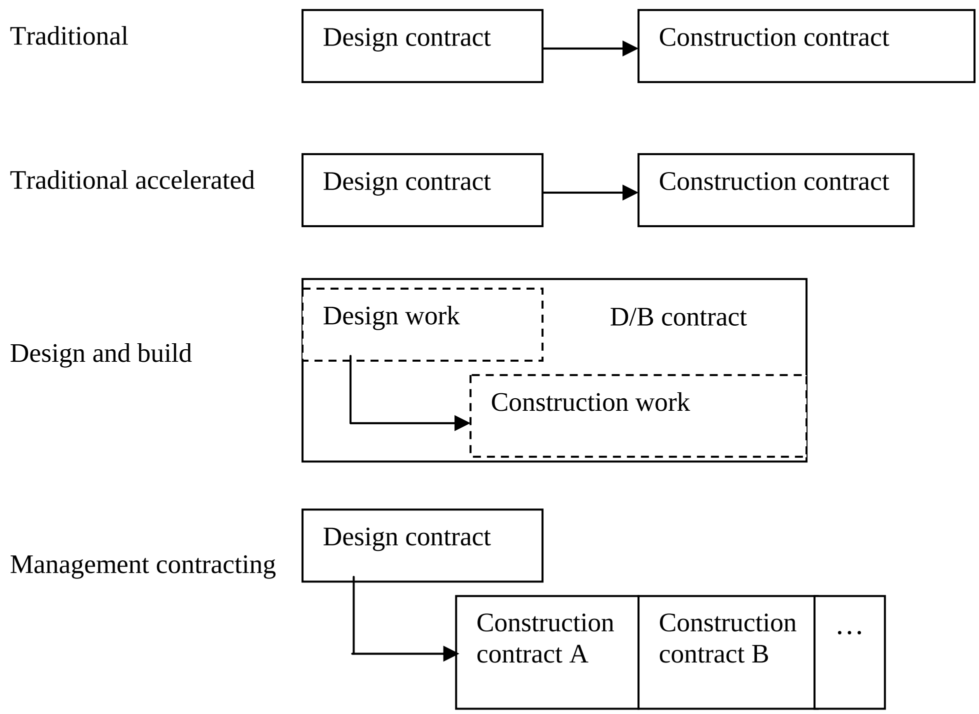

Figure 2: Schematic Illustration of Project Process under Various Procurement Methods

Next, derivation of utility functions that represent a decision maker's value system is the focus of decision analysis under uncertainty and the theoretical foundation has long been laid (Raiffa 1968). The present research proposes to use utility functions to represent a project owner's sensitivity to risks in time, cost and quality so as to convert the probabilistic estimates into utilities. The certainty equivalent technique in Lifson et al (1982) and existing mathematical forms can be referred to in deriving the utility functions. With respect to the utility function of time or cost, it is proposed to elicit three outcome points from the owner considering project conditions and experience from past similar cases: the best outcome with utility of one, the worst outcome with utility of minus one, and the threshold or neutral outcome with utility of zero. A utility function can then be obtained by fitting a smooth curve of a particular formula to these three points and the curve will be concave for an owner who is risk-averse. The time or cost utility for a procurement route is calculated using (1).

$$U = \int u(x) f(x) dx \qquad (1)$$

where x = project time or cost; $u(x)$ = utility function of x; $f(x)$= probability density function of x.

Concerning quality, it is proposed that related assessments be centered on two aspects: project design and project management. The quality utility of a procurement route depends on its ability to fulfill the owner's requirements on design such as design quality and flexibility to effect changes in handling complexities, as well as requirements on management such as quality certainty, clear responsibilities of project members, and ability to transfer risk. Each procurement route is assessed using the fuzzy logic in the following steps.

1. Define fuzzy membership functions for the inputs and the output

For each input variable, design and management, a fuzzy set family consisting of membership functions for high, medium, and low are defined using the triangular function. For the output variable, quality utility, a family consisting of fuzzy scores A, B, C, D, E are defined as crisp values of 1.0, 0.5, 0.0, -0.5, -1.0.

2. Define fuzzy rules and fuzzy operations

The fuzzy rules reflect the owner's project priorities in design versus management by the ranking of their combinations in the form of IF .. THEN ., e.g. if design is good and management is average then rank is B. The Sugeno fuzzy inference system is used along with the weighted average method for defuzzification.

3. Produce quality utility by fuzzy operations over fuzzy rules

Upon consultations with experts, the scores for design and management each in the range of 0 to 100 are assessed and assigned to each procurement route as inputs. Then, the fuzzy logic defined above is used to process the inputs for obtaining each route's quality utility for the project conditions.

The relative importance weights for time, cost, and quality can be determined according to the owner's project goals using the analytical hierarchy process method. The weighted aggregate utility represents the final evaluation of a procurement route and the route with the highest utility is recommended for selection.

5. Illustrative Example

A local authority is planning for an incineration and recycling plant project that consists of a boiler section and an ash storage section within a multi-story reinforced concrete structure. The budget for the project is NT$1.5 billions (1NT$≈0.03US$) and the owner requires the project to be completed within 900 days, making it a fast-track one with significant schedule risk. The project cost and time estimates based on the traditional procurement method are prepared first using the probabilistic estimating techniques mentioned previously. Cost estimates for project components are made in ranges of quantities of work, e.g. square meters of floor, and unit prices. The probability distributions for total cost for each procurement method are then obtained; their means and standard deviations in $NT10,000 are shown in Table 1. Compared to the traditional procurement method, the traditional accelerated method is expected to increase cost by 10% of labor cost, i.e. 10%*30%=3% of total cost, the design/build method requires an extra cost of 2.5% due to expected higher bids, and the management contracting method requires additional 2% cost for the service of the management contractor. Next, the probability distributions for project duration for each route are obtained; their means and standard deviations in days are shown in

Table 1. The probability of completion within the deadline is only 0.587 for the traditional method, but it increases to 0.827 for the traditional accelerated method that employs overtime work in a crash construction program. The durations for the design/build and management contracting methods are shorter because of concurrent design and construction, but the duration for latter is slighter longer due to more interfaces and tendering activities.

The square polynomial is used for modeling the utility functions and is solved with three elicited points. The time utility function thus obtained is $u(x)=-1.5*10^{-5}*x^2+0.0185x-4.5$ for $u(500)=1$, $u(900)=0$, and $u(1000)=-1$, while the cost utility function is $u(x)=-1.667*10^{-9}*x^2+0.000417x-25$ for $u(130000)=1$, $u(150000)=0$, and $u(160000)=-1$. The time and cost utility values of each procurement method are then obtained using Equation (1) along with the above utility functions and probability distributions; the results are also shown in Table 1. The quality utility of each method is obtained based on the scores assigned for design and management and considering them equally important; the results from fuzzy inference are shown in Table 2. The weights for time, cost, and quality for the project are determined by the owner at 0.45, 0.25, and 0.3, respectively, reflecting the priority in time. Lastly, the weighted total utility values for the traditional, traditional accelerated, design/build, and management contracting methods are assessed at 0.23, 0.21, 0.35, and 0.32, respectively, and thus the design/build method is recommended for selection.

Table 1: Estimated Time and Cost of Each Procurement Method For Example Project

Procurement method 1	Mean duration 2	Standard deviation 3	Time utility 4	Mean cost 5	Standard deviation 6	Cost utility 7
Traditional	893	32	0.04	145382	8607	0.23
Traditional accelerated	868	34	0.24	149743	8865	-0.11
Design/build	840	34	0.44	149017	8822	-0.05
Management contracting	853	38	0.34	148290	8779	0.01

Table 2: Fuzzy Quality Utility of Each Procurement Method

Procurement method 1	Score for design 2	Score for management 3	Quality utility 4
Traditional	50	50	0.50
Traditional accelerated	45	40	0.42
Design/build	45	60	0.54
Management contracting	55	50	0.53

6. Conclusions

There are notable differences between the proposed model and previous multi-attribute utility models for evaluating project procurement methods. To determine the total utility of each method, the models in Love et al (1998) and Cheung et al (2001) acquired the utility scores of each procurement method through a questionnaire with experts without utility functions, so they are simple but more subjective. However, the present model is based on the project time and cost estimates of each procurement method and the utility functions to convert the estimates into utility scores, as well as fuzzy logic to obtain the quality utility. The various techniques used in quantifying effects of differences in project organization, process, and priority involve more calculations but make the evaluation more objective and flexible. Although the total utility of a procurement method as derived from the analysis does not consider external factors such as level of competition in bidding and competence of contractors that also influence project cost and performance, evaluation of alternative procurement methods based on the model should not lead to biased ranking. For the high schedule risk project in the illustrative example, the procurement method actually used was the design/build method, the same as recommended by the model. The proposed model of applying the utility theory along with quantification of time, cost, and quality while avoiding subjective assessment of utility scores has the potential for achieving a more consistent procurement method decision.

7. References

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