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# UTILITY-BASED MULTICRITERIA MODEL FOR EVALUATING BOT PROJECTS

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**Abstract.** Owing to the urgent demands for new developments and maintenances of the existing infrastructures under limited government budget and time, increasing BOT (build-operate-transfer) projects have been a significant factor affecting the economic developments in many countries. However, as BOT projects usually induce huge capital investments, government sectors must prudently evaluate the project feasibility from both financial and nonfinancial aspects before the implementation. Therefore, how to establish an objective evaluation model which can comprehensively assess the feasibility of each BOT project and determine the priority of its implementation has become an important issue. This study incorporates analytic hierarchy process (AHP) and utility theory to develop a utility-based multicriteria model for supporting the selection of BOT projects. A case study is provided to demonstrate that the implementation of the proposed model can effectively help decision-making teams participate in economical evaluations so that the feasibility of as-planed BOT projects can be determined and project priority can be set efficiently and consistently.

**Keywords:** BOT, utility, AHP, multicriteria analysis, evaluation, decision support.

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## 1. Introduction

Public infrastructures have been conventionally delivered by the public sector using the design-bid-build procurement system. With the increasing demands for new developments and maintenances of the existing infrastructures, public sectors are unable to provide sufficient funds to deal with the challenge (FHA 2005; Augenblic and Cluster 1990). To resolve the financial limitation and time pressure, the concept of public private partnership (PPP) has been adopted by many public sectors to launch infrastructure projects for private financial initiatives (PFI), which are collective terms for build-operate-transfer (BOT), build-operate-own (BOO), build-own-operate-transfer (BOOT), build-transfer-operate (BTO), built and transfer (BT), and operate and transfer (OT) etc. (Kumaraswamy and Morris 2002).

Traditionally, most of government projects are procured by competitive bidding system or qualification-based selection system, while price and contractors' qualifications are considered as critical factors in the contractor selection process (Lo and Yan 2009). For the public fund-raising projects, rigorous contractor selection process is expected to find right contractors and to assure quality products as well as successful projects. However, in addition to contractor selection, a successful BOT project requires more favorable conditions than public fund-raising projects. The project promoters should ascertain that the project be politically, socially, legally, economically, and financially viable (Abdel Aziz 2007). Before implementing BOT projects, the government must effectively evaluate the feasibility of each project to eliminate unqualified projects and execute the selected project progressively according to its capabilities. However, previous studies have indicated that existing feasibility studies were insufficient for detecting inappropriate BOT projects (CRANA 2002). The major challenge for BOT project evaluation is not only the considerations of financial factors but non-financial factors such as construction efficiency, service efficiency, local government's financial ability and etc. In the past BOT practices, governments depended upon project feasibility studies conducted by private consultants and mainly relied on experts' group decisions. Therefore, how to establish an objective BOT project evaluation model to comprehensively assess the feasibility of each project and determine the priority of implementation has become an important issue. Since the allocation of BOT projects induces significant capital investments and impacts on a country's economy, factors including economics and social developments should be broadly considered (Ginevicius and Podvezko 2009). In addition, multicriteria analysis method enables broad perspectives for the assessment and risk valuation is essential during the decision-making process (Sliogeriene *et al.* 2009; Shevchenko *et al.* 2008). Thus, this paper aims to develop a multi-criteria decision model by incorporating analytic hierarchy process (AHP) and utility theory to manage the visible, invisible or unquantifiable factors that affect the effectiveness of BOT projects. Through this research, the feasibility and priority of each planned BOT projects can be evaluated objectively. A real case of the national BOT sewerage system plan in Taiwan will be used to demonstrate the usefulness of the proposed model. The result is expected to be a valuable reference for both administrators and legislators to manage future BOT projects.

## 2. Model Overview

The whole process of the evaluation of BOT projects comprises of 4 steps as shown in Fig. 1. The practices of the evaluation of BOT projects are demonstrated by the case of BOT sewerage systems selection in Taiwan.

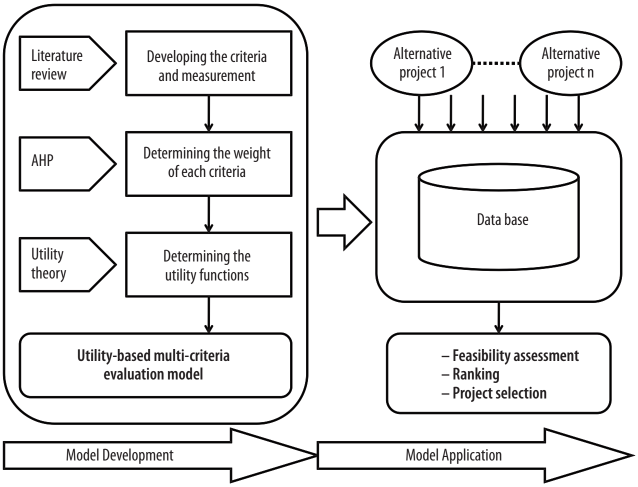

**Fig. 1.** The framework of BOT projects evaluation

Step 1: To sort out the influential factors for evaluating BOT projects based on literature review. In this paper, the criteria would be developed specifically for evaluating sewerage systems.

Step 2: To sum up the suitable criteria for establishing a systematic hierarchy as the source of questionnaire survey. AHP is applied to obtain the weighting ($w_i$) of each criterion.

Step 3: To define the content and quantifiable evaluation on range of each criterion, apply utility theory to build utility functions, and then use utility functions to determine numerical ratings ($u_{ri}$).

Step 4: To determine the weighted global utility (WGU) of each project; therefore WGU= $\sum w_i \times u_{ri}$. WGU is used for evaluating the feasibility of a target BOT project which is taken as the source of quantitative comparisons among all projects.

## 3. The Example Case

In Taiwan, the Executive Yuan has approved 36 BOT sewerage system projects and also initially reviewed the feasibility of adopting the BOT model for another 53 projects (CPAMI 2003). All these projects, 89 in total, are large in scale with a total cost over 100 billion US dollars and the completion of all projects is scheduled on 2014. However, according to the procedure specified in The Civil Participation in Sewerage System Construction Promotion Program, each project should be reviewed based on the feasibility evaluation and initial plans. Based on the framework described in section 2, the national plan of sewerage system in Taiwan is used as the example case of the model application.

## 4. Measurements of Evaluation Criteria

The US Environmental Protection Agency and International Development Institute have provided a list of criteria for state government to follow in the introduction of civil participation into construction of sewerage systems (USEPA 2000; IDI 2002). Based on the previous studies, a hierarchy of criteria can be developed. The hierarchy comprises of the overall goal, two groups of criteria (financial and non-financial) and finally eight evaluation criteria identified as follows:

### A. Financial criteria

1. Initial construction cost of the sewerage treatment plant:

Since a sewerage system can involve significant capital investments and construction works, the construction would usually be divided into several phases for handling the project risks and delivering sewerage system services phase by phase. The initial construction cost of a sewerage treatment plant can be evaluated by the following formula:

$$ICC = \frac{CCFP}{DCWP},$$

where $ICC$ = initial construction cost of the sewerage treatment plant (\$), $CCFP$ = the first phase construction cost of the sewerage treatment plant (\$), $DCWP$ = designed capacity of wastewater to be processed after the first phase construction (ton).

Although the initial construction cost for most wastewater treatment plant is usually high, a project should not be prioritized if $ICC$ is excessively high. Civil institutions may show higher efficiency in design, purchasing, and engineering of the systems with a lower value of $ICC$.

2. Cost of construction per household

$$CCH = \frac{TCC}{NH},$$

where $CCH$ = cost of construction per household (\$), $TCC$ = total construction cost (\$), $NH$ = number of households to be served (household).

$CCH$ reflects the overall assessment of the cost related with many impact factors such as construction difficulty, geologic structure, and others indirectly affect the construction cost.

3. Cost of prevalence rate improvement

$$CPRI = \frac{SDCC}{RH},$$

where $CPRI$ represents cost of prevalence rate improvement (\$), $SDCC$ represents sum of discounted construction costs in all years (\$), $RH$ represents ratio of households to be served to the total households around the nation (1%).

According to the government's estimation, the cost of enhancing 1% prevalence rate nationwide (including construction cost, interest cost of civil funds, and return) can be decreased by 5% each year until the same timeframe. $CPRI$ can be used as an index of government investment efficiency. A lower total cost indicates a higher effectiveness of prevalence rate improvement.

4. Unit charges of wastewater treatment

$$UCWT = \frac{UCWTP \times PTCP}{PTTC},$$

where $UCWT$ = unit charges of wastewater treatment (\$), $UCWTP$ = unit charges of wastewater treatment in each construction phase of the sewerage system (\$), $PTCP$ = planned treatment capacity in each construction phase of sewerage system(\$), $PTTC$ = planned total treatment capacity (ton).

$UCWT$ is an important parameter for reflecting the cost of wastewater treatment services. It involves construction amortization rates, operation and maintenance amortization rates, and household pipe connection amortization rates. For the government, lower $UCWT$ implies higher investment efficiencies.

### B. Non-financial criteria

1. Construction efficiency:

Construction efficiency of a sewerage system is measured by the duration required to accomplish 10,000 household connections after contracting (10,000 household is considered as 1 unit by the government). This parameter reveals the investment efficiency to be presented by a civil contractor. If the sewerage system can serve fewer than 10,000, this duration is estimated according to the proportion of the total household number of 10,000. When ranking the sewerage systems, those with a shorter duration would have a higher priority.

2. Pipeline service efficiency:

$$PSE = \frac{TPL}{TNH},$$

where $PSE$ = pipeline service efficiency, $TPL$ = total pipeline length (meter), $TNH$ = total number of households.

$PSE$ can reveal the unit service efficiency of each sewerage system, and also how much waste per unit can be carried by the sewer system. A low value of $PSE$ indicates higher concentration of population and also better service efficiency.

3. Design and construction quality:

$$DCQ = \frac{OMC}{UCWT},$$

where $DCQ$ represents design and construction quality, $OMC$ represents operation and maintenance cost (\$).

Experiences suggest that a well-designed and constructed sewerage system shows a relatively lower $DCQ$.

4. Local government's financial ability:

When the central government is unable to subsidize wastewater treatment and the user fee collected from the residents does not cover the expenses, the local government is still obliged to continuously operate the sewerage system. In this case, the wastewater treatment cost becomes a financial burden to the local government. Local government's financial ability can be measured by the ratio of the unit charges of wastewater treatment to the total budget of the local government as follows:

$$LGFA = \frac{UCWT \times AVW1}{AB},$$

where *LGFA* represents local governments' financial ability, *AVW*1 represents annual volume of wastewater treated in the first phase, AB represents the average current account revenue budget of the recent three years

A lower value of *LGFA* implies a lighter financial burden on the local government.

## 5. Weighting of Evaluation Criteria

An effective way to obtain group judgments for evaluating a complex problem is using a questionnaire to collect different viewpoints from a number of individuals. The statistics of the group response from the questionnaire may reflect the consensus of opinion and may be used as the basis of evaluation (Chao and Skibniewski 1992).

In this section, the opinions expressed by experts and evaluations on the weighting of each criterion are obtained through an AHP-based questionnaire survey. The questionnaires for collecting the consensus of opinion were mailed to 31 experts and scholars including (1) members of the sewerage system promotion committee in Construction and Planning Agency of Ministry of the Interior, (2) construction consulting firms involved in the design and execution of the current 36 sewerage systems, and (3) central government officials in charge of BOT sewerage systems administrations. Fourteen experts have completed and returned the AHP questionnaire survey. Opinions of all experts are aggregated to determine a set of weighting value of evaluation criteria ($w_i$) by four steps. First, on the basis of professional knowledge from the experts, pair comparison and matrix comparison of criterion items at each level in the hierarchy framework are carried out. Second, consistency of the eigenvector derived from the comparison matrix is examined. Third, the weighting of each criterion item can be identified. Because the priority of each element is developed systematically and objectively, the AHP results are reliable to provide problem solutions for multi-factors decision-making situations. Finally, a set of average weighting values is then calculated based on individual expert's results. The calculated results using AHP, which are listed in Table 1, show that the weighting value of each criterion is equal to the weighting of the main classification multiplied by weighting of sub-classification (CPAMI 2007).

**Table 1.** Weighting value of each criterion

| Code of the first level | Code of the second level | Code of the third level | Criteria | $w_i$ |
|---|---|---|---|---|
| C | C1 | C11 | Initial construction cost of the treatment plant | 0.1500 |
| | | C12 | Cost of construction per household | 0.1404 |
| | | C13 | Cost of prevalence rate improvement | 0.1546 |
| | | C14 | Wastewater treatment rates | 0.1751 |
| | C2 | C21 | Construction efficiency | 0.1125 |
| | | C22 | Pipeline service efficiency | 0.0875 |
| | | C23 | Operation and maintenance cost ratio | 0.0795 |
| | | C24 | Local government's financial ability | 0.1002 |
| | | | Total | 1.0000 |

## 6. Utility Function of Each Criterion

Utility theory has been an accepted approach used to provide an objective decision based on subjective, qualitative data (Cheung *et al.* 2002; Shen *et al.* 1998). The concept of "utility" was originally proposed in economics to measure the preferences of consumers as a unit of personal welfare. Utility theory requires utility functions that quantify qualitative decision criteria. Utility functions are used here for considering individual preference and attitude towards risk by decision makers when selecting an appropriate scale within the risk ranges. The utility functions can also be used to convert the evaluation score of each criterion into comparable ratings.

The utility function for each criterion has been built by applying the utility function technique of straight-line relationship (Dozzi *et al.* 1996). Based on the historic records of public fund-raising sewerage system projects, the threshold and the most preferred point of previous experience for each criterion are calculated so that the utility functions can be determined.

If $y_m$ is the most preferred point of previous experience, then $u_{ri}(y_m)=1$; $y_T$ is threshold point, $u_{ri}(y_T)=0$; moreover, utility function of straight-line relationship is $u_{ri}(y_i)=Ay_i+B$. Thus, constants A and B can be calculated and the computation is shown as following equation:

$$u_{ri}(y_m)=1$$

$$u_{ri}(y_T)=0$$

$$u_{ri}\left(y_i\right)=Ay_i+B=\left[\frac{1}{y_m-y_T}\right]\times y_i-\frac{y_T}{y_m-y_T}, \tag{1}$$

where $y_T$ = threshold point, $y_m$ = the most preferred point of previous experience.

The utility function for each criterion is identified and listed in Table 2. Since all the coefficients in Table 2 are extracted from the historic records of public fund-raising sewerage systems, these utility functions are representative to be the basis for evaluating BOT projects based on the weighted global utility (WGU) as shown in Eq. (2):

$$\text{WGU}=\sum_{i=1}^{n}\left(u_{ri}\times w_i\right). \tag{2}$$

The WGU of each evaluated project can be calculated using the above equation. Decision-makers can make judgments on each BOT project according to WGU; a higher WGU indicates more overall project feasibility for BOT approach.

**Table 2.** Utility function of each criterion

| Code of the criterion | $y_T$ | $y_m$ | Utility Function |
|---|---|---|---|
| C11 | 19323.644 | 29.834 | $u_i\left(y_i\right)=-0.0000518y_i+1.001546306$ |
| C12 | 58599.235 | 62.572 | $u_i\left(y_i\right)=-0.0000171y_i+1.001068932$ |
| C13 | 685.600 | 463.960 | $u_i\left(y_i\right)=-0.0045118y_i+3.093304458$ |
| C14 | 31.173 | 26.070 | $u_i\left(y_i\right)=-0.1959824y_i+6.109260167$ |

*End of Table 2*

| Code of the criterion | $y_T$ | $y_m$ | Utility Function |
|---|---|---|---|
| C21 | 5.250 | 5.000 | $u_i(y_i) = -4y_i + 21$ |
| C22 | 1.557 | 0.928 | $u_i(y_i) = -1.59y_i + 2.47$ |
| C23 | 0.296 | 0.242 | $u_i(y_i) = -18.6667455y_i + 5.525271643$ |
| C24 | 0.018 | 0.008 | $u_i(y_i) = -98.2604796y_i + 1.772848292$ |

## 7. Model Application

In this section, 8 BOT projects (respectively for the north, central, and south Taiwan) listed in the third-phase national construction plan are used to illustrate how the proposed model can be applied to objectively select feasible projects and determine the implementation priority for supporting the government's policy. Each BOT project is evaluated using the proposed model to derive the utility value of each criterion and WGU.

As shown in Table 3, the original BOT plans are arranged sequentially by locations. Although the government has gathered the necessary information regarding financial and non-financial perspectives, the original BOT plans are difficult to evaluate and compare objectively on the same basis. Thus, the government should heavily rely on the group decision making mechanism based on invited experts' opinions, even though each expert's decision is subjective. Since the decision mechanism incorporated less supporting quantitative models and numerical analysis, the mechanism would be a descriptive decision model that the rationale and consistency of decisions can't be properly justified.

Different from the aforementioned descriptive decision model, the proposed model enables decision makers to implement a normative decision model. The expected performance of each project from different aspects is listed in Table 3. Every project's expected performance is then converted to a WGU shown in Table 4. Based on the WGU of BOT projects, the project feasibility and utility can be evaluated objectively. Since the proposed model is developed by benchmarking previous public fund-raising projects, a project with positive WGU represents a feasible BOT plan which is expected to generate more benefits than using public fund-raising method. On the contrary, a project with negative WGU represents that the project is not favor BOT approach and might generate worse performance than using public fund-raising method. According to the aforementioned decision rules, 4 feasible BOT projects are identified, while the other 4 projects are not considered beneficial for the government by adopting BOT approach. Clearly, the proposed decision model generates useful signals for the government to re-evaluate unfavorable BOT plans before implementation.

In addition to supporting the evaluation of BOT project feasibility, the evaluated WGUs of BOT projects can be used to support the decision of priority setting. A project with higher WGU is suggested to be implemented with prior order. According to the decision rule, the priority of all BOT plans can be objectively and efficiently reordered based on their WGUs.

**Table 3.** Estimated performance of different BOT projects

| Project location | Project name | Criteria | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | C11 | C12 | C13 | C14 | C21 | C22 | C23 | C24 |
| North Taiwan (Taipei area) | Dansui | 29.41 | 62.57 | 439.4 | 28.01 | 5 | 0.93 | 0.44 | 0.01 |
| | Rueifang | 50.23 | 112.2 | 943.4 | 49.26 | 8 | 2.82 | 0.26 | 0.01 |
| | Sanying | 31.14 | 78.27 | 623.2 | 36.57 | 5 | 1.38 | 0.24 | 0.01 |
| Central Taiwan (Taichung area) | Taichung | 28.51 | 46.44 | 340.9 | 23.17 | 4 | 1.01 | 0.21 | 0.05 |
| | Fengyuan | 30.33 | 71.99 | 472.5 | 28.71 | 5 | 1.62 | 0.49 | 0.02 |
| South Taiwan (Kaohsiung area) | Shihlong river | 37.18 | 89.78 | 701.0 | 38.15 | 6 | 2.65 | 0.24 | 0.02 |
| | Daliao | 39.53 | 118.3 | 822.6 | 54.21 | 7 | 3.41 | 0.22 | 0.02 |
| | Gangshan-Chiautou | 33.38 | 103.4 | 716.6 | 37.16 | 6 | 2.83 | 0.22 | 0.02 |

As shown in Table 4, Taichung sewerage system project has the highest expected utility by BOT approach (WGU = 1.240). This BOT project should have the first priority to be implemented. The project that has the second priority for implementation is Dansui sewerage system project (WGU = 0.636). For other projects, the government can easily set their sequences for implementation based on their WGU ranking. Although some projects having negative WGUs would not be expected as effective via BOT, those projects still can be ranked and properly arranged a sequence for other considerations, such as promotion on specific region development, whether the BOT project is feasible or further evaluations needed.

**Table 4.** Decision supports for BOT project selection

| Project location | Project name | WGU | Feasibility of the BOT plan | Ranking based on WGU | Ranking based on experts' group decisions |
|---|---|---|---|---|---|
| North Taiwan (Taipei area) | Dansui | 0.636 | Feasible | 2 | 2 |
| | Rueifang | –1.791 | Not recommended | 8 | 8 |
| | Sanying | 0.448 | Feasible | 3 | 4 |
| Central Taiwan (Taichung area) | Taichung | 1.240 | Feasible | 1 | 1 |
| | Fengyuan | 0.320 | Feasible | 4 | 3 |
| South Taiwan (Kaohsiung area) | Shihlong river | –0.365 | Not recommended | 6 | 6 |
| | Daliao | –1.548 | Not recommended | 7 | 7 |
| | Gangshan-Chiautou | –0.358 | Not recommended | 5 | 5 |

Note that the same BOT plans shown in Table 4 have been evaluated by the government's research based on experts' group decisions, which is the formal and a prudent evaluation taken by Executive Yuan (CPAMI 2007). In the group decision process, the same evaluation criteria and weightings were adopted. For each criterion, every project was individually reviewed and ranked by the expert group. Thus, the overall ranking of projects can be determined, even though experts' judgments were one of the critical parts in the group decision process. As shown in Table 4, we found that the priority set based on the proposed model with WGU generates a very similar result as the original evaluation made by the government's research (Among 8 BOT projects been evaluated, 6 projects have the same ranking, while the other 2 projects have switched rankings).

In summary, the case study reveals three major advantages of the proposed model in supporting the government's decisions. First, the proposed model can save significant time and cost consumed by the process of experts' group decisions, including expert invitations, meeting and communications, and other administration procedures. Thus, the proposed model can improve the efficiency of the decision-making process. Second, the proposed model enables decision-makers to examine their preferences and the decisions can be logically reviewed. Thus, human errors and mistakes can be reduced and the consistency of decisions can be improved. Third, the WGUs derived from the proposed model can reveal the advantages and shortcomings of each BOT project on the same basis. It can provide the rationale as well as the justice of the public policy and reduce underlying political burdens.

## 8. Conclusions

BOT projects usually induce huge capital investments and affect the national economic development significantly. To promote and ensure the success of a government's BOT policy, rational, consistent, and transparent decisions for selecting appropriate projects constitute critical factors, while sufficient numbers of responses from related experts can't be ignored as well. The proposed evaluation model using the utility function shows the advantages that it can overcome the difficulties of building a multicriteria model for supporting BOT project selections so that the rationale, consistency, and transparency of decisions can be improved.

With the aid of the utility-based model, the case study demonstrates that decision-makers can improve the quality and efficiency of their decisions because of full participation by all members involved in the evaluation process and the integration of their opinions. Since the proposed model standardizes the evaluation process and enables decision-makers to adjust decisions according to their preference and considerations, the conclusions made in the decision-making process can be logically reviewed to ensure consistent decisions. This advantage would be specifically critical for getting consensus and improving the effectiveness of the public decision-making.

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## SEP PROJEKTŲ VERTINIMO MODELIS PAGRĮSTAS DAUGIAKRITERINE NAUDINGUMO TEORIJA

**M.-R. Yan, Ch.-S. Pong , W. Lo**

**Santrauka.** Dėl esamos infrastruktūros plėtros ir atnaujinimo būtinybės, esant ribotam valstybės biudžetui ir laikui, SEP (Statyba-Eksploatacija-Perdavimas) projektų vykdymas ženkliai prisidėjo prie daugelio šalių ekonominių pokyčių. Dažnai SEP projektai reikalauja didelių kapitalo investicijų, todėl valstybės sektorius turi įvertinti projekto įgyvendinimo galimybes tiek finansiniu tiek nefinansiu aspektu. Koks turi būti objektyvaus vertinimo modelis, kuris leistų visapusiškai įvertinti kiekvieno SEP projeto pagrįstumą ir nustatyti jo įgyvendinimo prioritetus? Šiame straipsnyje, naudojant analitinę hierarchinio proceso (AHP) struktūrą ir naudingumo teoriją, SEP projektų atrinkimui sukurtas daugiakriterine naudingumo teorija pagrįstas modelis. Skaitmeninis pavyzdys įrodo, kad siūlomas modelis gali sėkmingai pagelbėti atrenkant ekonomiškai efektyvius SEP projektus.

**Reikšminiai žodžiai:** SEP projektai, naudingumas, AHP, daugiakriterinė analizė, įvertinimas, sprendimų parama.

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