A Framework of Optimization Model for Decision Makers on Super-Project Management

スーパープロジェクトのマネジメントに必要な意志決定者のための最適化モデルに関する研究

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ABSTRACT: Super-projects are built by investing large amounts of money, time and manpower. These irreversible projects have a profound impact on the market price and are very difficult to manage because the definition of objectives by decision makers at each level of the super-project is so different. In this paper, the author tries to develop an optimization model which is based on cost-benefit-analysis and risk-analysis for super-project decision makers on procurement management with due consideration of the hierarchical organization of the construction industry.

Key Words: Optimization, Decision Makers, Super-Projects,

1. Introduction

Construction projects, such as transportation, power and telecommunication are developed to achieve common social and economic objectives. There are several sizes of constructions including residential housing constructions, commercial constructions, heavy constructions or super-scale projects. To improve the quality of life, super-projects which involve many decision makers, different interest groups, related laws, and regulations are being constructed all over the world (Conway 1996). One super project in Taiwan, Taipei's subway project (Mass Rapid Transit systems), has already doubled its budget and schedule, and still nobody knows when it will be completed (Stepard 1996). Another super-project, the US Navy "Big Dish" project of 1948-1962, is another record of failure (Feld 1997). Both projects began with a dream but have failed economically through underestimating the

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impact of the project scale. To explain the failure, economists try to analyze the problem as a supply-demand situation caused by the project investment and construction. One internal discussion paper from the World Bank (Jack 1993) shows that super projects will substantially impact on the market price and macro-economy to an irreversible extent. The reasons behind the failure of super projects might be various, but important one is the enormous hidden cost and/or risks of super-projects that are not conceived during preparation stage. For example, if the capacity of whole industry is not enough to construct a certain super project, the cost of importing materials and attracting workers from other industries will be higher than the normal situation. Furthermore, the extra cost of training can not be ignored. However, research has not considered the multi-level organization of super-projects in the construction industry. Cohon (1978) tried to solve this problem by researching the multi-objectives optimization. Since then, more and more engineers have focused on the multi-level problems between the decision makers (e.g. Wen and Yang 1990). Some researchers have tried to solve these problems by using a "fuzzy" approach; this is to find the ranks of utility among different viewers by reasonably subjective judgment (Shin, Lai and Lee 1996). Despite these efforts, engineers still know very little about the likely effect of super projects, and none the economic or engineering research has contributed little to the solution of the problem of super-projects. Therefore, the author will propose an optimization model which is based on cost-benefit-analysis and risk-analysis in this paper for super-project decision makers with due consideration of the hierarchical organization of the construction industry.

2. What Is Super-Projects:

The definition of the super projects is varied, but the simplest and clearest way came from Conway (1993) as, "*Global super projects are those projects that involve an investment of at least $1 billion and/or a technological breakthrough of global significance*". Although these projects are built to achieve the dream of human beings, their risk is higher than normal projects'. The famous super-projects included the Beijing-Hong Kong Railroad, the Channel Tunnel, the Denver International Airport, and so on. However, most super-projects have a poor performance in budget controlling or scheduling. For instance, the budget of rapid systems project (1962) in San Francisco Bay Area increased to 1.3 times. The budget was spent 1.26 times for one nuclear power plant project in Minnesota (1977). Some economical failure cases of super projects are giving in Table 1.

Table 1. Some Failure Cases of Super Projects

Project	**Cost Overrun**	**Country /Location**
Rapid Transit systems (1972)	1.3 times	US/ San Francisco Bay
Nuclear Power Plant (1977)	1.26 times	US/ Minnesota
Rapid Transit Systems (1983)	more than $2 billion	US/ Washington Area
Eurotunnel (1993)	2 times	England-France/ England Strait
Mass Rapid Transit Systems	More than 2 times	Taiwan /Taipei

Because the failure of super projects has a substantial impact on economic and social activities, some institutes have been established to find the method for managing these projects efficiently (Morris: 1987): for example, "The American Society for Macro-Engineering", "Large Scale Programs Institute in the United States", and "The Major Projects Association" in England. Besides that, the World Development Federation, an international federation of individuals and organizations involved in large-scale development projects, has held several times of the conferences for these special projects. These organizations which were established for improving the performance of management on super projects are giving in Table 2.

Table 2. The Present Organization for Super Project Management

Name of the Organization	***Country***
The American Society for Macro-Engineering	US
Large Scale Programs Institute in the United States	US
Le Centre International de Reserche et Formation en Gestion des Grands Projects	Canada
Canadian Major Projects Association	Canada
Spanish Society for Marco-Engineering	Spain
The Major Projects Association	England

3. Who are the decision makers on this model

Generally speaking, the main institutions for public works include the Economic Agency, the Ministry of Construction and construction departments. A construction department has to submit the detailed construction plans to the Economic Agency and the Ministry of Construction for the project budget. Although the decision makers for a super project are many, the final decision maker herewith means the chairman of construction department rather than others. The decision maker of this model is given in figure 1.

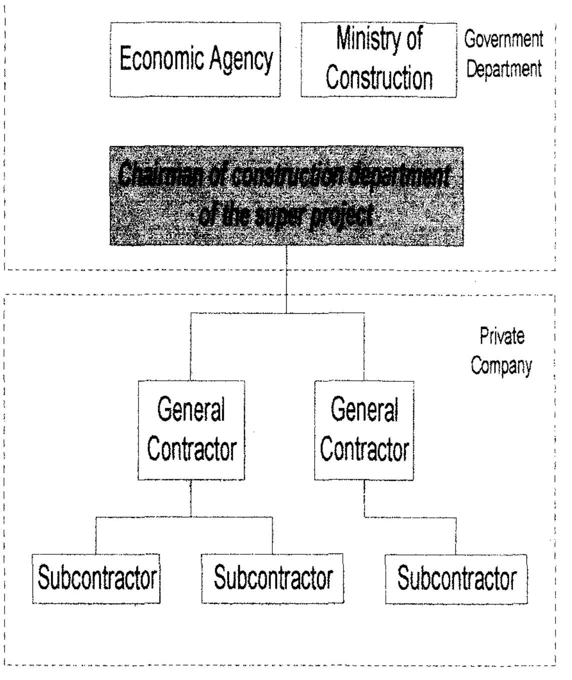

Figure 1. The decision maker on this model

In addition, unlike the decision makers in other institutions, the main objectives of the construction departments are to finish the project on time within the budget. [1] The

[1] Based on the interview (1997 May) with some decision makers of the Economic Agency, the Ministry of construction, construction companies and construction departments in Taiwan (Republic of China), the objectives of these institution are quite

objectives of the decision maker are to maximize the benefit and to minimize the risk in this proposed model. The objectives of these decision makers are given in Table 3.

Table 3. The Objectives of Multi-level Decision makers

The Decision Makers	***Main Objectives***
The Economic Agency (Government Department)	● Economic Efficiency (Max. Social Profit) ● Equity Objectives
The Ministry of Construction (Government Department)	● Promoting domestic construction firms ● Enlarging totally capacity of domestic construction industry ● Controlling the risk
Construction Department (Government Department)	● Procuring the project smoothly (Min. Inflation) ● Completing projects earlier within the budget and schedule (Max. Profit and Min risk)
Contractors (Private Company)	● Maximizing profit ● Enlarging capital scale

4. What is The Model

(1) The introduction of this model

After the managers of the construction department get permission for a super project, they have to submit a detailed plan for the project budget. This includes the expected tendering prices and the schedules of each small contract of one big super project. To realize the integrated performance of the whole super project, each small contract will be considered as one section of the whole contract package. The main idea of this proposed model is using cost-benefit-analysis model to assess the integrated profit to all the different contracts and using the risk-analysis model to evaluate the uncertainty of the super project. Furthermore, it will try to find the optimal combination of contract-awarding strategy for the whole contract-package.

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different, for example, the social benefit is the main concerns of the Economic Agency.

(2) The framework of the model

The proposed model comprises two sections that are conceptual systems and mathematical model.

a) Conceptual systems

The first section, conceptual systems, consists of three parts, 'output design', 'input design' and 'management design'.

'Output design' is concerned with the attributes of the benefit of the project, such as the earlier operation with the cheaper fee for subway system.

'Input design' means the investment cost for approaching the goal, like the construction payments for each section. For example, the reconstruction of interstate highway 10 in the United Stated was finished within 66 days. The incentives of the project were $200,000 a day for early bonus and $200,000 a day for late penalty in the project. [2]

To analyze the attributes of output and

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[2] The data based on the interview (1997 Mar.) with the engineer of the California Department of Transportation (Caltrans).

input design, procedures of ascertain-classify-assess are needed. The first procedure, ascertaining, means to find related attributes and test by a certain standard. In the next stage, classifying means to separate the attributes into different groups. Then, the principle of 'willingness to pay' will be applied in assessing the contribution of these attributes. (Nas 1996)

Finally, the third part, 'management design', aims to maximize the profit and minimize the risk of the impact of the super project through the cost-benefit-analysis and risk-analysis.

b) Mathematical model

After the conceptual systems, input-output-management, have been decided, the mathematical model could be formulated. Two parts evolve the mathematical model: objective function and decision variables for the decision maker. Although mathematical model is not ideals but it can help the decision maker to clarify their goal and find the reasonable solution. Therefore, operational usefulness is the main idea of this mathematical model. Since the real problem of the super project sometimes comes from the impact of the project itself, the feedback action should be included in this model for checking the fluctuation of construction price and refining the optimal solution. The framework of the model is given in figure 2.

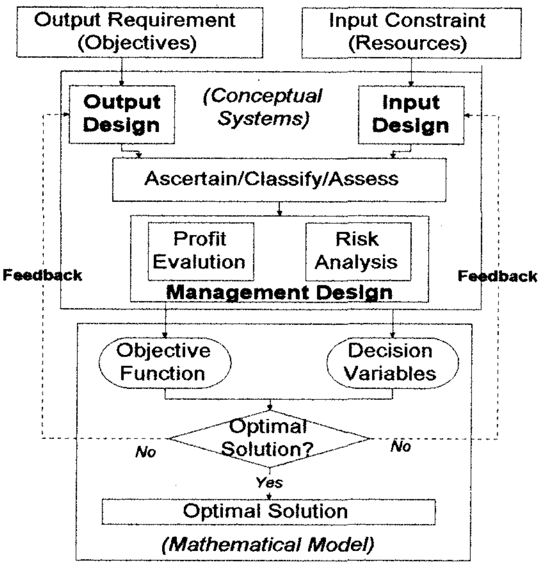

Figure 2. The Framework of the Model

(3) The formulation of the mathematical model

The mathematical model that is used to assist decision makers in making a cost-benefit-analysis and a risk-analysis decisions here is based on net present value model (NPV). In addition, this proposed model presented an approach to combining net present value model with the nonlinear programming method for evaluating the optimal solution.

a) The profit and risk

To quantify the attributes, profit is defined as subtracting costs from benefits (Barfield 1991) and risk is defined as the measurement of a loss, identified as a possible outcome of the decision (Byrne 1996). 'Loss' may be as perceived as actually reduced profits between designed profit and real discount profit, as given in Figure 3. Real discount profit is the profit when designed profit is taken at a discount by the impact of super projects. Designed profit is the expected one before construction.

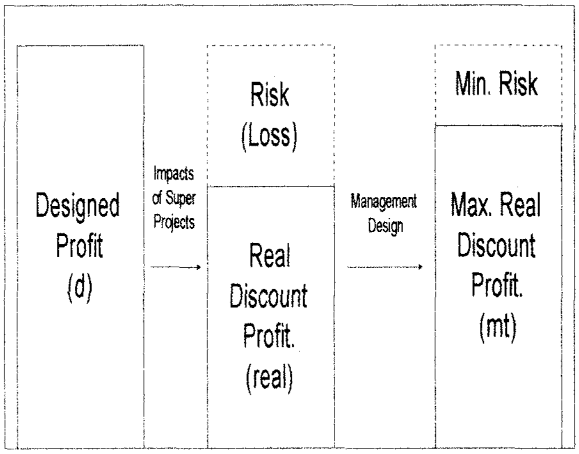

Figure 3. Relationship between Designed Profit and Real Discount Profit

Then, the fundamental equation can be given as the following:

Designed Profit (P) =
Designed Benefit (B) – Designed Cost (C)

Risk (R) = Loss (L) = –△Profit (–△P)
= ***Designed* (*P*) –**
***Real Discount* (P^{real})**

The whole idea above mentioned can be summarized as:

$$P = B - C \qquad (1)$$

$$\Delta P = P^{real} - P \qquad (2)$$

$$R = L = -\Delta P = -(P^{real} - P\ ) \qquad (3)$$

Moreover, to have more clear idea about loss and profit when considering the cost and benefit, the following equation is given:

$$\begin{aligned} L &= -\Delta P_t = -(P_t^{real} - P_t) \\ &= (B_t - C_t) - (B_t^{real} - C_t^{real}) \\ &= (\frac{C_t^{real}}{C_t} - 1) \times C_t - (\frac{B_t^{real}}{B_t} - 1) \times B_t \\ &= \beta_t \cdot C_t - \alpha_t \cdot B_t \end{aligned} \qquad (4)$$

'α' means the discount index of benefit and 'β' means the discount index of cost under the uncertainty of the super project. For instance, the real cost will increase because of the inflation of construction price and the real benefit will decrease because of the delay of construction. Until now, capital letter means function. The meaning of 'L', 'P', 'B', 'C' are loss, profits, benefits and costs respectively.

b) Two objective functions

The first objective of management is to maximum profit, and the objective function of maximizing profit 'Z_p' is defined as follows when considering the net present value of the whole profit:

$$\text{Max.} \quad Z_p = \sum_{t=0}^{T} \frac{B_t(b_i, w_i^1(s_t)) - C_t(c_j, w_j^2(s_t))}{(1+r)^t} \qquad (5)$$

Here, 'w[3]' that is decided by the procedure of ascertain-classify-assess means the relative weights of attributes for decision makers. Moreover, 'r' means the interest rate and

[3] The present method for assessing the weights of indirect benefits and costs included : Property Value Approach, Land Value Approach, Wage Differential Approach, Travel Cost Approach, Replacement Cost Approach, Relocation Cost Approach, Shadow Projects Approach and Contingent Valuation Method

's' means the size of the projects. Also 't' means the time , and then, 'i' and 'j' mean the numbers of attributes for a different factor in a certain period. For instance, it can be a certain section (or a contract) when dividing one super large project. Here, a small letter means parameter.

Moreover, the objective function of minimizing risks 'Z_R' are defined as

$$\text{Min } Z_R = \sum_{t=0}^{T} \frac{L_t}{(1+r)^t} = -\sum_{t=0}^{T} \frac{\Delta P_t}{(1+r)^t}$$

$$= \sum_{t=0}^{T} \frac{\beta_t \cdot C_t(c_j, w_j^2(s_t)) - \alpha_t \cdot B_t(b_i, w_i^1(s_t))}{(1+r)^t} \quad (6)$$

Therefore, both of objective function can be derived as the function of cost and benefit.

c) The interactions among multi-level (from single level to multi-levels)

It has generally been considered that there is no relationship between the objective of higher and lower level decision makers. So far, the discussions are limited to a single level. However, the objective functions for the hierarchical organizations of construction industry might be more complicated than this single goal. It has got to be something to do with the interactions among the multi-level managers. The objective functions and mathematical equations of two levels Decision making are given in Table 4.

Table 4. The Mathematical Equations and Functions of Higher and Lower Level Decision Makers

Mathematical equations/functions between higher and lower levels	Conceptual Systems
$B_t^H(w_i^H(s_t), b_i^H)$ $B_t^L(w_i^L(s_t), b_i^L)$	Output Design [Benefit(B)]
$C_t^H(w_j^H(s_t), c_j^H)$ $C_t^L(w_j^L(s_t), c_j^L)$	Input Design [Cost (C)]
1). Profit Max. $Z_p^H(B_t^H, C_t^H)$ Max. $Z_p^L(B_t^L, C_t^L)$ 2). Risk Premium Min. $Z_R^H(\alpha_t \cdot B_t^H, \beta_t \cdot C_t^H)$ Min. $Z_R^L(\alpha_t \cdot B_t^L, \beta_t \cdot C_t^L)$	Management Design [1. Profit(P)] [2. Risk (R)]

Here, 'Z^L' means the objective function of the lower level decision and 'Z^H' means the objective function of the higher level decision. Moreover 'B^H' and 'B^L' mean the benefit of total benefit for higher and lower level. 'C^H' and 'C^L' mean the total cost for higher and lower level. 'b^H' and 'b^L' mean the benefit of one section for higher and lower level. 'c^H' and 'c^L' mean the cost of one section for higher and lower level. When a client is the higher level decision maker, the higher level's benefit means the benefit after operation and the cost means the expenditure for procuring the projects as the tendering price. On the other hand, the lower level's benefit means the cash inflow from the project payments and cost means their expenditure for constructing the project. Since these interactions, such as the ceiling price of the project from higher level and the price of 'willingness to pay' from lower levels, between higher and lower levels, the decisions at a higher level will become constraints at a lower level. Furthermore, the lower level's decision to require the higher tendering price might cause an increase in the higher level's cost. The interactions of multi-level decision making are given in Figure 4.

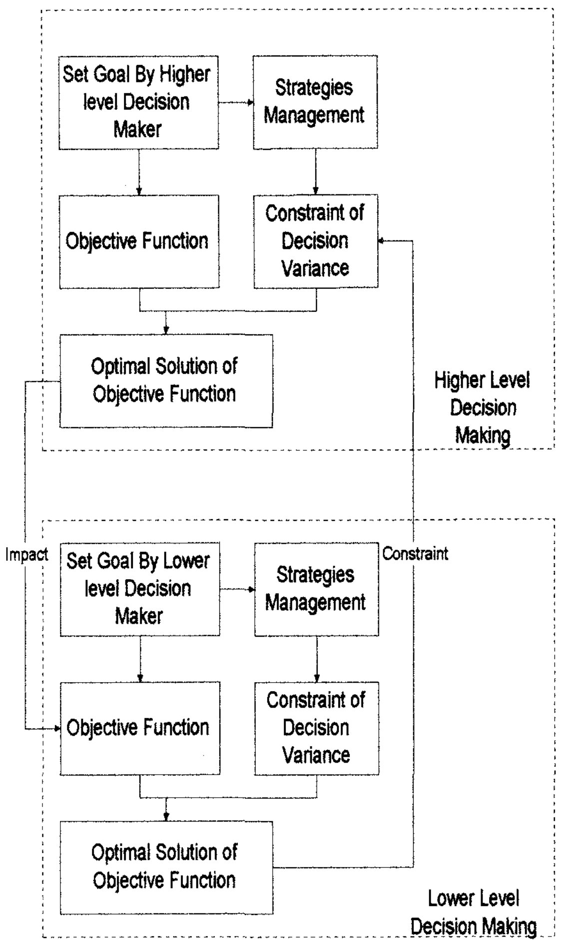

Fig. 4. The Interations of the Multi-Level Decision Making

c) The impact of super projects on price fluctuation (from static model to dynamic model)

Until now, the whole system is based on a fixed price during the whole procedure. However, the fixed price model can not function well on the issue of super project management, in particular, when construction prices fluctuate because of super projects. It means the cost of construction will become variance by the impact of different bidding strategy of super-projects. For example, when the total size of required output in a certain period is higher than the total capacity of the construction industry, the price will be pushed higher than normal. Then the higher level manager has to expend more cost between the designed cost and the real cost. Therefore, it is necessary to adjust the cost-benefit-analysis to the risk-analysis because of the shortage of the fixed price model..

5. Conclusion

The aim of the paper was to develop an optimization model for multi-level decision makers on super projects. It was generally considered that the management of super projects is particularly difficult when considering the different objective functions among the multi-level managers and the impacts of the project on the market price change. The proposed model tries to address these two problems. As explained above, a mathematical output-input-management model was developed to clarify the procedure of decision making. The model needs to be tested for its applicability through quantification of variables in the mathematical model. Once it is proved to be practicable, decision makers can get a clearer idea interactions among multi-levels and can achieve the optimal solution at each level. Furthermore, the future task of this research is to quantify the dynamic system for improving this model to reduce the risk of price fluctuation.

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