

A Decision Support System for Contract Size in A Superproject – A Case Study of MRT Project in Taiwan

大規模プロジェクトにおける発注規模の決定方法に関する研究
– 台湾MRTプロジェクトをケーススタディとして

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Abstract: One of the most common strategies for public owners constructing a superproject is to divide the whole project into several contracts. Because of the dividable nature of these projects, a trade-off analysis between advantage in larger contract size (i.e. economies of scale) versus the risk premium of uncertainties (i.e. diseconomies of scale) is carried out to determine the optimum size of contracts. To evaluate both the risk premium and the economies of scale, the paper presents the Contract Size Decision Support System (CSDSS) using the existing net present value method by incorporating probability distributions of risk premium. The CSDSS also suggests practiced measures to facilitate in establishing an optimum contract size strategy through linear programming.

Key words: contract size, decision support system, expected net present value, linear programming

1. Introduction

To reduce construction time and to increase efficiency of construction, and as well as protect small businesses entities in

construction industry, one of the most common strategies of public owners is to divide a superproject into several lots or phases. However, inefficiency of sharing resources and equipment occurs when ever contract sizes are divided into excessively small phases. To determine the optimal contract size, some research has reported that construction cost can be reduced as contract size increases in Japan. (Tsunemi, 1995) In addition, some research has

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recommended that the impact of contract size on bidding price is positive. (Park, 1968) On the other hand, some research has pointed out the risk of cost growth and delay when contract sizes become bigger. (Hewlett, 1994)

To summarize these efforts, the author will propose a contract size decision support system that allows construction personnel to make more informed decisions regarding contract size. The system determines contract size through analysis of available information and formulation of summaries that aid in decision making processes. The Contract Size Decision Support System (CSDSS) is a decision support system that creates a consistent, comprehensive capital controlling analysis that helps to integrate all the actions taken to mitigate the economies of scale and diseconomies of scale during a decision process.

As the case study, the program processes a historical record of estimated budget, contract value, actual cost, estimated schedule, and actual time at Taiwan's Mass Rapid Transit system (MRT) projects. The databases contained in the program are based on over 100 actual MRT contracts in Taiwan and were collected through the department of Taipei MRTS.

2. Methodology

To analyze the trade-offs between different contract size strategies, the author augments the existing net present value method by adding probability distributions, and suggests

measures to decide optimum contract size strategy by linear programming.

At the outset, the author makes a distinction between four different contract sizes - tiny, small, medium, and large - for MRT projects. First, tiny contract size is defined as a contract value less than 1 billion yen. Small contract size is defined as a contract value between 1 billion yen and 2 billion yen. Furthermore, medium contract size is located from 2 billion yen to 4 billion yen and larger contract size means contract value bigger than 4 billion yen. The definition of different contract size is given as the following Table 1.

Table 1. Definition of Different Contract Size

Contract Size	Definition
Tiny Size	Less than ¥ 1 billion
Small Size	¥ 1 to 2 billion
Medium Size	¥ 2 to 4 billion
Large Size	Bigger than ¥ 4 billion

However, it is difficult area to determine the optimum contract size strategy because it requires one to consider a variety of important inter-related factors. One distinction is between economies of scale and diseconomies of scale. The concept of economies of scale seems simple: "Increasing a contract size decreases the average cost". At most point, a contract becomes so large that diseconomies of scale set in. Excessive size can bring complexity, loss of focus, and inefficiencies, which raise the average unit cost.

Here, the author summed up one measure (i.e. visible factors) as the economies of scale and three measures (i.e. invisible factors, cost overrun, and delay) as the diseconomies of

scale. Visible factors include direct cost, indirect cost, and administrative cost that can be calculated directly by cost estimation before awarding a contract. Some research, such as a report from Research Institute of Construction and Economy (RICE) in Japan, have paid more attention to this factor and made a simulation model. However in actuality, it is not end of story at all simple.

Invisible factors indicate bidding allowances between the government's estimation and contract value during the contract awarding stage. These indicate the extra allowance that government can obtain through open bidding. Most researchers emphasizing on competitive bidding models are in the groups. (Park 1968)

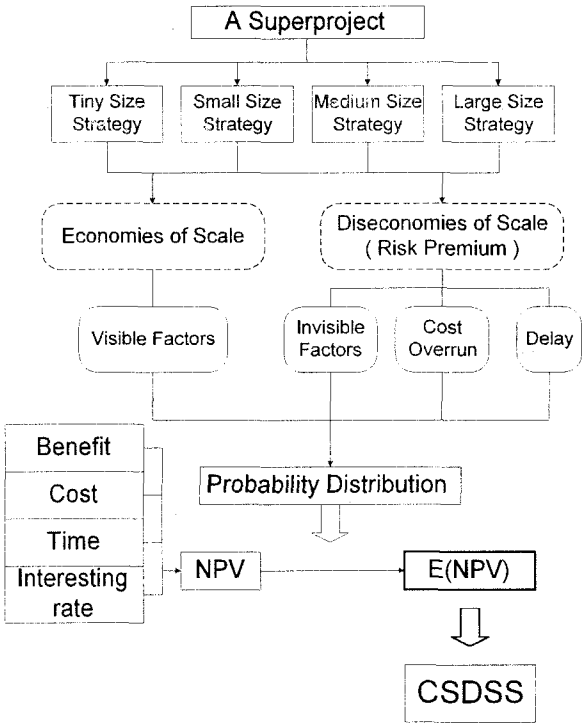


Figure 1. The Research Flowchart

Moreover, the author segmented another

two factors including cost overrun and time delay for the impact of diseconomies of scale in the CSDSS system. The research flowchart is shown in the following Figure 1.

3. Development of the CSDSS

(1). Expected net present value

Since the optimum contract size strategies are determined by several factors including involved works, time factors and risk premium, a more comprehensive method, expected net present value (ENPV), was applied by combining net present value and probability distribution of uncertainty to support decision makers. To develop the ENPV method, there are five main factors: benefit, cost, time, interest rate, and probability. The expected net present value was given as following equation (1):

$$E(NPV) = P * NPV = P * \sum \frac{(b - c)}{(1 + r)^t} \quad (1)$$

where,

E(NPV) = Expected Net Present Value

NPV = Net Present Value

P = Probabilities of the NPV

b = Benefit

c = Cost

r = Interest rate per interest period

t = Number of periods

In most cases, the method of work breakdown structure (WBS) is applied during the conceptual design phase. The objective of

developing a WBS is to study the elemental components of the project in detail. It permits the implementation of the “divide and conquer” concept. The WBS is a document that divides the project into major hardware, software, information, and service elements. These elements are further divided and a list is produced to identifying all tasks that must be accomplished to complete the project. Table 2 shows an abbreviated WBS for an MRT project in Taiwan.

Table 2. The WBS of Construction Cost for MRT Projects in Taiwan

	Factors	Elements
Construction Cost (CC)	Direct construction cost (DC)	Embankment, Elevated railway, Cut-and-cover method, Shield Tunneling, Environmental fee, Safety fee, Temporary construction fee, etc.,
	Indirect construction cost (IC)	Administrative fee, Consultant fee, Supervising fee, etc.,
	Cost Escalator (CE)	
	Contingency (CN)	

Based on the cost estimation handbook of public works by Executive Yuan in Taiwan, R.O.C.

Based on the structure exemplified at Table 2., the construction cost can be showed as following equation (2).

$$CC = \sum DC(s) + \sum IC(s) + CE(s) + CN(s) \quad (2)$$

where,

CC = Construction cost

DC = Direct construction cost

IC = Indirect construction cost

CE = Cost Escalator

CN = Contingency

S = Contract Size

Here, the process of payment to the contractor was divided into two stages such as prepayment and progress payment in order to simulate the actual situation of cash flow. Prepayment was paid at the beginning stage.

On the other hand, the benefit of the project is not directly related to the contract size because the benefit comes from service fees and releasing of traffic jams during operation stage. Because these benefits can not be obtained until the project is completed, benefits are calculated during the project's operation life. In addition, all benefits are represented by monetary terms. Therefore, benefit function can be shown as the following equation (3):

$$B = \sum b(t) = \sum \frac{b}{(1+r)^t} \quad (3)$$

where

B = Total benefit

b = Individual benefit

t = The inflow time (operation periods)

(2). Economies and Diseconomies of Scale

Construction operations are subject to a wide variety of fluctuations and interruptions.

Varying weather conditions, learning curves on repetitive operations, equipment breakdowns, management interference, and others are external factors that impact the production process in construction. Since construction projects are often associated with high degrees of uncertainty stemming from the unpredictable nature of construction, simulation techniques are needed to distinguish a risk premium for contract size strategies. Here, to simplify the simulation process, the impacts of contract size were divided into two parts such as the economies of scale and diseconomies of scale. The economies of scale means visible factors that can be analyzed by cost estimating process. Data for this part of the study was obtained using ratios in the handbook of cost estimation published by public owners. The diseconomies of scale were separated into invisible factors, cost overrun and delay. Unlike visible factors, these factors include more uncertain elements. These elements are represented by their expected value through their individual probability distribution. By summing up the probability distributions of the two measures, the probability of NPV can be obtained as the following equation (4).

$$P(NPV) = f(\omega, \gamma, \varepsilon, \eta) \quad (4)$$

where

ω = visible factors

γ = invisible factors

ε = cost overrun factor

η = Delay factors

Here, visible factors can be calculated through the cost estimating process. It means to

reduce estimated cost by sharing resources and equipment before awarding contract. For example, the cost efficiency of operating a shield machine or the administrative cost of coordinating inter-phases between contractors can be reduced as contract size increases. Therefore, visible factors can be expressed as parameters of the cost function. Moreover, the government's estimated cost (i.e. the budget) is always higher than the contract value. The gap between these two values was concluded as another factor in terms of diseconomies of scale because the contractor may required higher contract value when the contract size is larger. Furthermore, cost overrun and time delays in construction stage are another factors of diseconomies of scale in terms of risk premium. To sum up these factors, the following equation is applied (5)

$$\begin{aligned} AC &= f(IC_0, \omega, \gamma, \varepsilon) \\ &= IC_0 - C(VF) + RP(IF) + RP(CO) \\ B &= f(\eta) \end{aligned} \quad (5)$$

IC_0 = Initial Cost

$C(VF)$ = Cost Reduction of Visible Factor in Cost Estimation Stage

$RP(IF) = (BV - CV)/BV$ = Risk Premium of Invisible Factor in Bidding stage

$RP(CO) = (AC - CV)/BV$ = Risk Premium of Cost Overrun in Construction Stage

BV = Budget Value

CV = Contract Value

AC = Actual Completed Cost

Here, initial cost was a cost that was estimated without considering the visible

factors of economies of scale or diseconomies of scale. AC means actual completed cost and it includes the three factors: the visible factor, the invisible factors and the cost overrun factor. B means cash inflow with due consideration of time value of delay. By checking the outputs of the selected distribution model with analysis of historical records, a more realistic probability distribution can be discovered.

(3) .The Contract Size Decision Support System (CSDSS)

Now let us suppose that some contracts on the list of those being considered by combining independent, mutually exclusive, and interdependent contracts. The choice among such projects is an exercise in integer programming. Now a matrix consisting of i rows, j columns and k lines must be included.

The objective function is

$$\begin{aligned} \text{Max } Z &= \sum_{i=1}^m \sum_{j=1}^n \sum_{k=1}^o E(NPV)_{ijk} * X_{ijk} = \\ &\sum_{i=1}^m \sum_{j=1}^n \sum_{k=1}^o P_{ijk} * (NPV)_{ijk} * X_{ijk} \end{aligned} \quad (6)$$

Subject to

$$\sum_{i=1}^m \sum_{j=1}^n \sum_{k=1}^o P_{ijk} * C_{ijk} X_{ijk} \leq M \quad (7)$$

$$\begin{aligned} X_{ij} &= 0, 1 \text{ for } i = 1, 2, \dots, m; \\ j &= 1, 2, \dots, n; k = 1, 2, \dots, o \end{aligned}$$

where

Z = The net present value accruing to the ($I*J*K$) region

$E(NPV)_{ijk}$ =Measure of expected net present value
 $= P(NPV) * NPV$

$X_{ij \ k}$ =Decision variable, 0 or 1

C_{ijk} =Expected cost of contract

M =Budget

m = Number of rows (different contract size strategies)

n =Number of rows (independent contracts in a contract size strategy)

o =Number of columns (mutually exclusive contracts)

By definition, no more than one mutually exclusive contract may be chosen per row. Therefore, another constraint must be added.

$$\sum_{k=1}^o x_{ijk} \leq 1 \quad (8)$$

Moreover, the interdependent contract will put into consideration such as contract 1 will have no reason for existing unless the contract 2 is built, the relationship can be expressed as a constraint

$$-x_2 + x_1 \leq 0 \quad (9)$$

where x_1 and x_2 are the decision variables.

Since simulation methods can provide the needed computational power and flexibility to implement diseconomies and economies of scale in a manner consistent with contract size strategies, the author presents the following case study to demonstrate the effective of simulation in solving this problem.

4. Case Study

In Taiwan, per capita income has been over \$10,000 dollars and the quality of life is more enhanced than ever. The mass rapid transit systems (MRT) that will serve the six million residents in the Taipei metropolis will meet the transportation needs of eight major corridors in metropolitan Taipei, strengthen the link between downtown and satellite towns and cities, and promote the overall development of the Taipei City. The initial network was to span 88 kilometers in Taipei City and Taipei County.

The systems have three different types of construction: at grade, elevated, and underground. The choice depends on available rights of way, construction costs, passenger convenience, and environmental impacts. The budget for the initial Network of MRT is about \$ 18 billion dollars. This expenditure will be shared by three authorities Central Government, Taipei City Government and Taiwan Provincial Government in a proportion.

The study project under consideration within a database of project budget, contract value, actual cost, estimated time, and completed time is a MRT project in Taiwan. To simplify the system, lump-sum contract with competitive bid was applied in these cases.

(1) Visible Factors

To obtain the visible factor in terms of economies of scale, construction cost was separated into four main works as direct cost, indirect cost, cost escalator, and contingency.

Furthermore, cost escalator and project preserve will be merged to indirect cost to simplify the system.

Direct cost was divided into auxiliary equipment of shield (SH), miscellaneous of main structure & excavation (MSE), miscellaneous of Shield driven tunnel (ST), and related works (RS) in this case study. To multiply these works by the unit price, the ratio of unit construction cost in terms of 400, 600, 800, 1000, 1200, and 1400 meters shield tunnel was discovered by one research from Taiwan's Executive Yuan as following table 3.

Table 3. Direct Cost V.S. Project Length

Project Length (PL)	Percentage of Construction Cost			PL(N) / PL(400)
	SH	MSE	ST	
N=400 m	22.1	54.3	13.5	1.000
N=600 m	17.5	60.7	11.8	0.842
N=800 m	14.5	64.9	10.6	0.764
N=1000m	12.3	67.8	9.8	0.716
N=1200m	10.7	70.0	9.2	0.685
N=1400m	9.5	71.7	8.7	0.662

Source: One research plan from Executive Yuan of Taiwan, R.O.C.

On the other hand, indirect cost will be based on the standard ratio of administrative fee from the Central Government of Taiwan as the following Table 4.

Table 4. Administrative Fee V.S. Budget

Project Budget	Max. Ratio
< 5 million NT\$	4.5%
5 to 25 million NT\$	4.0%
25 to 100 million NT\$	3.0%
> 100 million NT\$	2.5%

Source: Executive Yuan of Taiwan, R.O.C.

(2) Invisible Factors

To simulate the invisible factors that define the gap between the government’s budget and the contract’s value, historical data of 100 Taiwan MRT contracts were analyzed by statistical regression. The relationship was given as the following Figure 2.

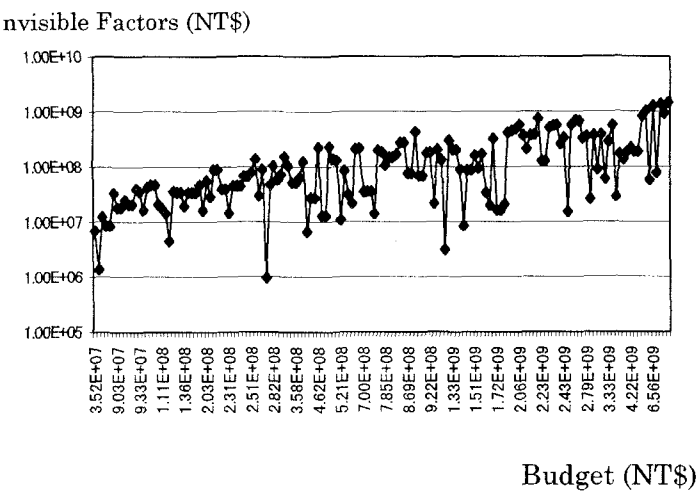


Figure 2. Relationship between Invisible Factors and Budget

Furthermore, by classifying the contract size into four groups as mentioned earlier and analyzing their relationships by regression, invisible factors could be obtained as the following table 5.

Table 5. Probability of Invisible Factor

(AV-CV)/BV	Contract Size Strategies			
	T	S	M	L
0-0.1	13.30%	33.30%	60.00%	64.70%
0.1-0.2	33.30%	33.30%	13.30%	23.50%
0.2-0.3	26.60%	13.30%	13.30%	5.90%
0.3-0.4	6.60%	13.30%	13.30%	5.90%
0.4-0.5	20.00%	6.60%	0.00%	0.00%

Where,

$(BV-CV)/BV = \text{Invisible Factor}$

BV = Budget Value

CV = Contract Value

T = Tiny Contract Size Strategy

S = Small Contract Size Strategy

M = Medium Contract Size Strategy

L = Large Contract size Strategy

(3) Cost Overrun

Cost overrun factor means the gap between contract value and actual completed cost. It can be summed up based on Actual data such as the following Table 6.

Table 6. Probability of Cost Overrun Factor

(AC-CV)/BV	Contract Size Strategies			
	T	S	M	L
0-0.1	60.00%	73.30%	26.66%	64.70%
0.1-0.2	13.30%	20.00%	46.66%	23.50%
0.2-0.3	20.00%	6.60%	20.00%	11.76%
0.3-0.4	6.60%	0.00%	6.66%	0.00%
0.4-0.5	0.00%	0.00%	0.00%	0.00%

Where,

$(AC-CV)/BV = \text{Cost Overrun factor}$

AC = Actual Complete Cost

(4) Time Delay

Time delay factor is analyzed as the following Table 7.

Table 7. Probability of Time Delay

E(AT/ET)	Contract Size Strategies			
	T	S	M	L
1-1.5	35.7%	40.0%	40.0%	42.1%
1.5-2	28.6%	20.0%	20.0%	26.3%
2-2.5	14.3%	33.3%	33.3%	21.1%
2.5-3	21.4%	0.00%	6.70%	5.30%
3-3.5	0.00%	6.70%	0.00%	5.30%
3.5-4	0.00%	0.00%	0.00%	0.00%

Where,

$$E(AT/ET) = \text{Function of Delay} \\ = (\text{Actual Time}) / (\text{Estimated Time})$$

AT = Actual Time

ET = Estimated Time

5. Experimentation for Case Study

The guiding motivation underlying the experiments was to explain the concept of the optimal contract size for decision makers. Since the CSDSS incorporating the economies and diseconomies of scale through the measures of expected net present value, the results of the system can be obtained as the concave curve as the following Figure 3.

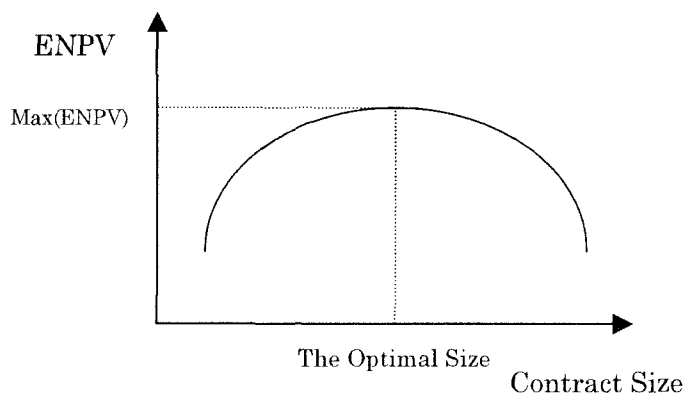


Figure. 3. The Concept of the Optimal Size

6. Conclusion

This paper presents both the conceptual model of the decision support system and one case study to explain the advantaged and disadvantaged factors in larger contract size. By incorporating these factors to the practiced measures (i.e. ENPV), the decision makers can have more clear idea in terms of determining the optimal contract size strategy.

The proposed contract size decision support system (CSDSS) can support decision makers the efficient and effective information of contract size selection, but a decision. By incorporating the visible factors, invisible factors, cost overrun factors and time delay factors, the expected net present value of different options in contract size can be obtained. In addition, the optimal contract size can be decided by using the 0,1 linear programming with due consideration of the constraints that government may need to take into account.

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大規模プロジェクトにおける発注規模の決定方法に関する研究 ー台湾MRTプロジェクトをケーススタディとして

通常の大規模プロジェクトにおいて、公共発注者は一つの大きなプロジェクトを幾つかのサイトに分割し、発注を実施する。プロジェクトを分割発注することにより、より大きな発注規模による有利性（規模の経済）と、不確実性に起因するリスクプレミアム（規模の不経済）を巡り、発注規模の最適化に関する二律背反的分析が行われることになる。このリスクプレミアムと規模の経済性を評価するため、当論文では、リスクプレミアムの確率分析を加味した期待現在価値測定法を用いることによる、発注規模決定支援システム(CSDSS)について述べる。また CSDSS は、線形分析を通して最適発注規模戦略の確立を促進する現実的方策についても言及している。

キーワード：発注規模、決定支援システム、期待現在価値、線形分析