OVERALL BENEFIT-DURATION OPTIMIZATION (OBDO) FOR OWNERS IN LARGE-SCALE CONSTRUCTION PROJECTS

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ABSTRACT : This paper aims to consider an overall benefit-duration optimization (OBDO) problem for the sake of maximizing owner's economic benefits, whilst considering influences of schedule compression incurred opportunity income on the profitability of a large-scale construction project. Unlike previous schedule optimization models and techniques that have focused on project duration or cost minimization, with greater weight on contractors' interests, OBDO facilitates owner's economic benefits through overall benefit-duration optimization. In this paper, the objective function of OBDO model is formulated. An example is illustrated to prove the feasibility and practicability of the overall benefit-duration optimization problem. The significance of employing OBDO model and future research work are also described.

Key words : *Overall benefit-duration optimization, network compression, opportunity income, owner's economic benefits, large-scale construction projects*

1. INTRODUCTION

Optimization of large-scale construction projects with the objective of optimizing overall economic benefits for owner is an important task. But there are not many optimization methods used in both academia and practice for this particular purpose. Although there are some methods used in construction scheduling such as time cost tradeoff, resource constrained and time constrained scheduling, all of these are limited to the construction phase and have a commonly single objective of minimizing construction cost or duration, favoring the interests of contractors. Few researchers extended their studies into the domain of schedule optimization for the economic benefits of project owners. In practice, contractors only need to consider time cost tradeoff problems of how to balance available resources and costs, and then schedule the project within the appropriate project duration at minimum cost. However, owners have to consider not only the factors involved in the construction phase, but also other influencing factors beyond project completion, such as bank interest savings and future revenue, which influence the project profitability. Different schedules lead to different costs, investment distribution and economic benefits. It is therefore necessary to consider an innovative optimization technique that is different from the traditional ones, favoring the economic benefits of owners. This paper aims to contribute an overall benefit-duration optimization model through a new scheme of network compression, while considering maximization of owners' benefits in large-scale construction projects.

2. BACKGROUND

2.1 Duration Cost Relationship of a Construction Project

Since duration and cost are closely related, and sometimes, crucial to the successful implementation of construction projects, it can be assumed that a close relationship exists between cost estimate and schedule. The major cost of a construction project consists of direct and indirect costs. The resources distributed to each activity of a project network determine the direct cost. Indirect costs are overhead costs. These two cost parameters are of great importance to project practitioners who strive to minimize the total cost while completing the project within the contractual duration. Total cost is the sum of these two cost parameters and customarily increases with compression in project duration. Large-scale construction projects are unique in terms of capital requirement and implementation period. Minimizing cost is therefore a primary objective in the planning and scheduling of such projects. Construction schedulers have to face the decisions of selecting appropriate resources to perform the activities of a project. Different decisions will ultimately cause different corresponding duration and project cost. Selecting the most cost-effective way to complete a project is desirable for project schedulers. In practice, schedulers perform the so-called time cost tradeoff analysis to lower construction cost without impacting the project duration.

2.2 Time Cost Tradeoff and Network Compression

Given a construction project network with a set of activities to be completed according to their precedence relationships, the objective of time cost tradeoff is to select appropriate resources to complete the tasks within the required duration and at minimum costs [1]. Time cost tradeoff problem is one of the most important goals of construction scheduling. In general, there are tradeoffs between time and cost to complete each activity of a project [2]. A number of methods and solutions have appeared in the literature for the time cost tradeoff problems in recent decades. Their solutions are proposed to minimize construction cost, considering influencing factors within the construction phase, with greater weight on contractors' interests. However, few researchers extended their studies into the domain of optimizing economic benefits for owners, whilst integrating related influencing factors within the life cycle of large-scale construction projects.

Network compression was originally developed along with the critical path method (CPM) for planning and controlling large-scale projects [3]. Compression in CPM means selecting the activities with the lowest cost slope along the critical path. Generally, compressing network inevitably incurs additional expenditure as more resources are consumed for the earlier completion of the project. The objective of network compression is to crash selected activities to balance direct and indirect costs and thereby minimize the increment of overall project costs until the target duration is reached. There are many alternatives as each individual activity may be crashed. The cost of the alternatives is calculated from the time cost relationship of each activity, and the least expensive alternative is the best solution. The compressing procedure is repeated until the required compression time is reached and the total cost increment is minimized.

3. PROBLEM STATEMENT

3.1 Characteristics of Large-scale Construction Projects

Large-scale construction projects are unique and varied due to the number of variables, numerous constraints and other factors. Each characteristic has its influence on project duration, cost and profitability. Some characteristics that are closely related to the research objectives are as follows:

1. **Capital Intensive -** Each activity on the network of a large-scale construction project can only be completed with substantive amount of working capital [4]. Different activities on the network have to be fulfilled synchronously. Therefore, large-scale construction projects are capital intensive.
2. **Long term Implementation -** The development of a large-scale construction project is spread over a long period of time since it involves the accomplishments of hundreds of activities.
3. **Network Complexity -** Since many activities are involved in the network of a large-scale construction project and each activity has dependent or independent interrelationships with others, the project network is usually complicated and complex.

3.2 Different Economic Perspectives of Contractors and Owners

With the inevitable increase in size and complexity of modern construction projects, contractors and owners need to have a more comprehensive understanding of all the relevant economic aspects of their works. They must be able to implement a high degree of cost and schedule control, not only in respect of the schedule progress and the cost of construction but also over the influences arising from the economic environment within the lifecycle of the project. In the implementation of a large-scale construction project, a number of objectives exist. Meeting a certain contract date, confining expenses to a fixed budget and minimizing cost can all be objectives. These objectives are often conflicting because of different participants' economic perspectives on the project cost and duration. Owners and contractors have their own different economic perspectives, which demand an appropriate balance between project cost and project duration [5]. A construction contractor has objectives for his own cost control, which will differ from those of the owner's project management [6]. As far as project cost and duration are concerned, the priorities of contractor and owner inevitably differ. In practice, a contractor's objective is to select appropriate resources to complete the activities of the project network within the required duration at minimum cost. Therefore, construction solution with minimum cost is critical to the economical perspective of contractors. On the other hand, owners who finance large-scale construction project with bank loans face the constant pressure of shortening project schedules as it is economically beneficial since this operation introduces earlier income flows and more interest savings. In today's fast paced and inflationary construction industry environment, time is often the essence. Owners have been increasingly placing greater demands on contractors to complete projects earlier [7]. This is because time is critical for owners in attaining 'first in the market' advantage over competitors. Owners will most likely suffer the loss of expected benefits as a direct result of delays in putting the construction facility or product into service [8]. In such a situation, economic viability of a large-scale construction project is crucially dependent on shortening the construction duration at the expense of increasing the cost by a reasonable percentage. Therefore, under the condition that potential income and interest saving exceed the increased total cost, compressing project network can be more lucrative for owners to generate potential benefits. However, the shorter project duration that the owner desires might not suit the contractor's economic considerations.

3.3 Opportunity Income and Owner's Incentive for Network Compression

Opportunity income stands for the summation of interest saving and future revenues from project network compression. Interest saving is a major concern of owners. On a billion dollar hydropower plant project with an estimated duration of ten years, the funds invested during the first year at 7% interest will double by the end of the project [9]. The owner does not receive any return on investment until the project is commissioned and used. The owner wants the project completed in the shortest time that his financing ability allows [10]. Basically, investment by an owner in a large-scale construction project, though it does not earn any profit before the project is completed, has the cost of interest. The owner's interest saving from expedited project schedule can reach a significant amount in a large-scale construction project. The interest saved by the owner and future revenues from network compression offers him an opportunity income. Project network can be compressed so that the owner can commission the project earlier than originally scheduled and put the facility into use at the earliest date. Thus when interest on investment and predictable future revenues is considerable, it is advantageous for owners to determine not only the total construction cost but also their overall economic benefits for each alternative funding scheme and then select the optimal solution. Ironically, though some owners have recognized the significance of the timing of income and expenditure, owners have not always been able to formalize their methods of dealing with it. Some owners' accounting systems do not even facilitate this. Moreover, in practice, cost planners are not always able to demonstrate any benefit from optimizing owner's overall benefit in relation to time.

4. OBJECTIVES

This paper aims to maximize the owner's overall benefits by compressing the project schedule to an optimal limit under the condition that the compression incurred opportunity income exceeds the cost increment, considering future revenue and interest saving due to the earlier completion. The objectives are as follows:

- Formulate the objective function of overall benefit-duration optimization;
- Develop an associated model based on the formulated objective function, balancing cost, duration and the owner's benefit;
- Apply the optimization model on an example and prove its feasibility and practicability.

5. OVERALL BENEFIT-DURATION OPTIMIZATION (OBDO) FOR OWNERS

5.1 Definition and Assumptions of OBDO

For a large-scale construction project, given a normally scheduled network with a set of activities to be completed according to their precedence relationships and under the condition that the compression incurred opportunity income exceeds the cost increment, the objective is to make a sequence of decisions to crash activities on the network and hence compress the schedule to a desired limit in term of benefit and duration where the optimal overall economic benefit of owner is reached. This problem is referred to as overall benefit-duration optimization.

The OBDO concept is valid only if the following assumptions or requirements are met:

1. The compression incurred opportunity income must exceed the total cost increment. The OBDO model seeks to compress a project network with a minimum increase in the cost by buying time along the duration where the maximum profit of the owner is obtained.
2. OBDO model assumes unlimited resource availability. Unlike time cost tradeoff (TCT) problem that require contractors to consider resources constrained solutions during compression, OBDO assumes that the resources are unlimited. This assumption enables independent crashing of activities; crashing one activity will not interfere in the crashing of other activities.
3. No requirements of cost minimization within target duration. The traditional TCT problems primarily concern with the tradeoff between compressed duration and the consequent increase in total cost. OBDO considers the maximization of economic benefit for owners.
4. Interest rate and future revenue are predictable. The summation of interest saving and future revenue forms the opportunity income and influences the overall economic benefit due to the network compression. Therefore, these two parameters are assumed to be predictable based on the historical data and the industrial environment.

5.2 Objective Function of OBDO

Objective function of OBDO model is:

$$\text{Maximize} \quad \Delta Z = \Delta O_c - \Delta C_t \quad (1)$$

$$\Delta O_c = \Delta R_c + \Delta I_c \quad (2)$$

The selection of the objective function is based on the microeconomic concept of marginally increasing or decreasing utility for varying levels of input. ΔO_c, ΔR_c, ΔI_c, and ΔC_t denote marginal opportunity income, marginal revenue, marginal interest saving and marginal total cost, respectively. ΔZ denotes marginal economic benefits. T_t is the optimal compressed duration where the maximized benefit is obtained. In relation to the compressed duration, C_t is assumed to be nonlinear since the total cost increment of successive compressions is not constant. Generally, the total cost increment of succeeding compression is more than that of the preceding compression because of more investment of working capitals. Therefore, the C_t curve is assumed to be concave, with a minimum (Fig. 1). To satisfy the condition that O_c exceeds C_t, the O_c curve is assumed to be higher than the C_t curve. The precise C_t curve is difficult to obtain either in practice or from theoretical analysis.

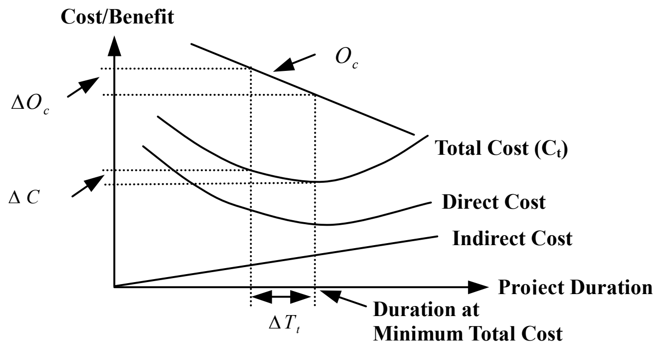

Figure 1. OBDO for Owners

The increased total cost, ΔC_t, is expressed as follows:

$$\Delta C_t = C_c - C_n = \sum C_{ci} - \sum C_{ni} \quad (3)$$

$$\sum T(j) = T_t \quad (4)$$

where i denotes total number of activities on the network.

j = subset of crashed activities on critical path.

C_n = total cost at normal schedule.

C_c = total cost after project network compression.

T_t = total optimal compressed duration of the project.

Equation 3 shows that if the normal schedule is compressed, the total project cost increases. The increased total cost can be calculated by subtracting normal total cost from compressed total cost. The compressed duration of the project network is the summation of crashed times of all activities on the critical path (Eq. 4). In addition, the objective function is subject to the following constraints:

$$\Delta O_c > \Delta C_t \quad (5)$$

$$\Delta Z, \Delta O_c, \Delta R_c, \Delta I_c, T(i) \geq 0 \quad (6)$$

$$T_c(i) \leq T(i) \leq T_n(i) \quad (7)$$

Revenue, R_c, and interest saving I_c, both increases with schedule compression. The summation of these two parameters is considered as marginal benefit of owner if the project completes before the normal schedule at minimum total cost. Obviously, under the condition that ΔO_c is more than ΔC_t, the objective is to use these two parameters to maximize the overall economic benefit to the owner.

5.3 Formulation of OBDO Model

The formulation of the OBDO model needs to consider three factors: project duration, total construction cost and owner's economic benefit. Project duration and total cost are determined by the length of the critical path in the network and the sum of the activity costs respectively. The OBDO model uses marginal economic benefit of owner as the objective function to be maximized. For the duration factor, OBDO model crashes the times of the individual activities in the network. Often the performance of some or all activities can be accelerated or the duration compressed by allocating more resources at the expense of higher total cost. Many different combinations of activity crashing can yield different desired project duration at different project costs. Since different combinations of possible duration of the activities can be associated in a project, the problem is to consider the best one from these combinations. Determining the best set is the primary purpose of the OBDO model. The cost factor is also dependent on the combinations of expenditures for the activities on the network. Typically, a construction project is broken down into activities to which resources can be assigned and costs estimated. Total cost consists of direct cost and indirect cost. OBDO model is employed to identify several activities on the critical path of the network and enumerate possible alternatives of crashing time units to these activities. Among the feasible alternatives with the same compressed duration, the associated total costs are evaluated and the one with the least cost increment is more desirable. The summation of compression incurred additional cost and the originally planned total cost gives the final total cost of the compressed project. With reference to the owner's economic benefit, it is closely influenced by many factors, such as project duration, investment allocation, cost, interest rate, and future revenue. Since network compression incurred opportunity income exists, owners' benefit changes with the fluctuations of project duration. An owner may shorten the project duration so as to maximize the economic benefit by earlier collection of incomes after project completion.

The basic procedure of the OBDO model is illustrated in Fig. 2. Project schedule is compressed by crashing individual activities on network. More resources usage causes cost increment. However, under the condition that the compression incurred opportunity income exceeds the cost increment; a saving is achieved in the overall benefit of owner. The schedule is compressed until any other activity crashing results in an optimal solution where the increment of overall benefit will be offset by a sufficient cost increment. As the final output of OBDO model, the total cost, compressed schedule and owner's maximized economic benefit are gathered and exported for final decision making.

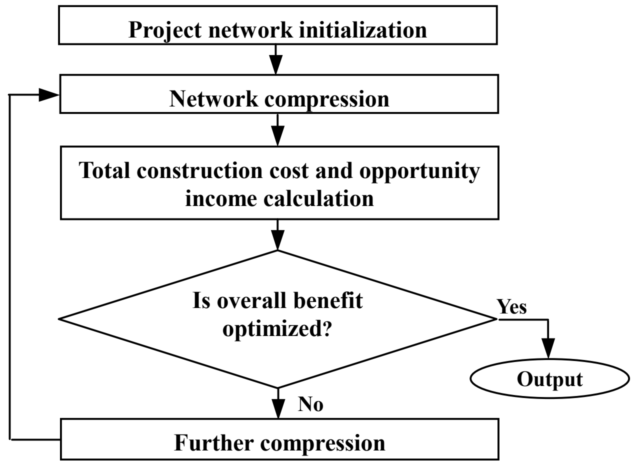

Figure 2. OBDO Model

6. EXAMPLE APPLICATION

A project network comprising 11 activities is represented in this paper. The direct cost has been estimated to be $845,500. The indirect cost is expected to be $2100/day. For simplicity, the relationship between cost and duration of individual activities is assumed to be linear. Information regarding the crashing ranges and the cost slope of individual activities is provided in Table 1.

Table 1. Data regarding crashing of activities

Activity (1)	**Range (Days)** (2)	**Cost Slope ($/day)** (3)
1-2	0	-
2-3	2	1,200
3-6	6	800
6-10	4	750
2-4	4	1,100
4-7	2	950
7-8	3	900
8-10	2	500
2-5	4	400
5-9	5	1,000
9-10	2	400

6.1 Time Cost Tradeoff (TCT) Solution

All Normal Solution

As shown in Fig. 3, the all normal solution of this project takes 90 days to complete. The critical path of the project is 1-2-3-6-10. The non-critical chains are 2-4-7-8-10 and 2-5-9-10 with total floats of 2 days and 10 days respectively.

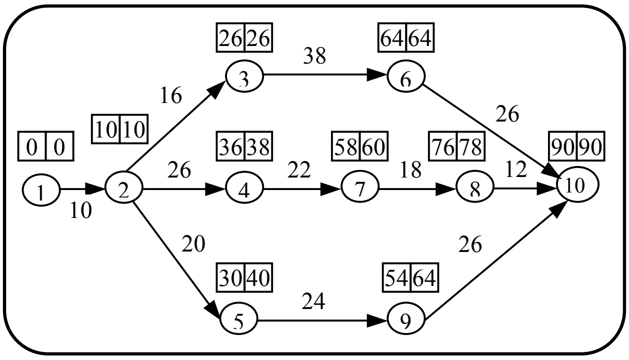

Figure 3. All Normal Solution

First Compression

Compression means crashing critical activity or activities with lowest cost slope, which bear the least cost increment. In this example, if n critical activities were compressed by one day each (duration would be n days shorter), to make sure the total cost does not increase, the summation of their cost slopes would be less than the indirect cost saving (n x \$2100/day). Therefore, in the first compression, activity 6-10 is selected and compressed by 2 days. The compressed network is shown in Fig. 4. The critical paths of the project are 1-2-3-6-10 and 2-4-7-8-10. The non-critical chain is 2-5-9-10 with total float of 8 days.

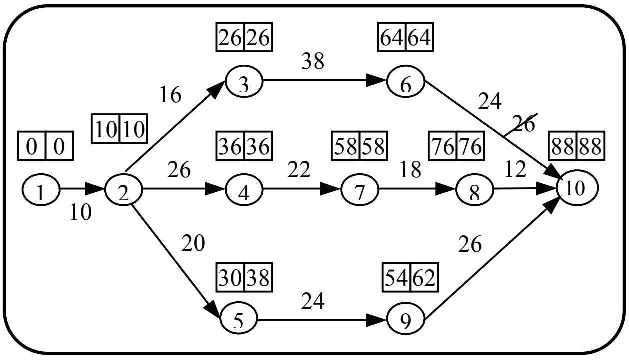

Figure 4. First Compression

Second Compression

There are two critical paths after the first compression. One is the original critical path 1-2-3-6-10. The other path is 1-2-4-7-8-10. To ensure further compressions, these two critical paths must be crashed together. The second compression comprises of the following: crash 6-10 (\$750) and 8-10 (\$500) by 2 days each; crash 3-6 (\$800) and 7-8 (\$900) by 3 days each; crash 3-6 (\$800) and 4-7 (\$950) by 2 days each; and crash 3-6 (\$800) and 2-4 (\$1,100) by 1 day each. After the second compression (Fig. 5), the project can be completed in 80 days, 10 days less than the all normal solution. All the three activity chains have become critical paths. If further compression is required, all the three paths must be compressed together. The summation of these three activities' cost slopes will exceed the indirect cost slope. That means further compression is not feasible to minimize total cost. The TCT solution shows that there is no further crashing possibility for the project because after the second compression, total cost will not have any margin to decrease but tends to increase (Table 2).

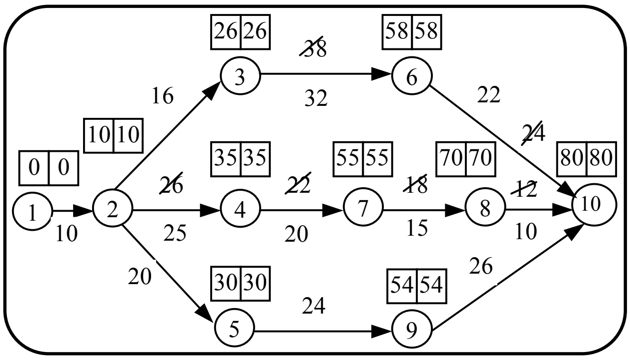

Figure 5. Second Compression

Table 2. Normal and compressed solutions

Items (1)	**Normal solution** (2)	**TCT solution** (3)
Project Duration	90 days	80 days
Indirect Cost	90×\$2,100 = \$189,000	80×\$2,100=\$168,000
Direct Cost	\$845,500	Total Crashing Costs: ∑ \$14,500 Activity 6-10 - 4 x \$750 = \$3,000 Activity 3-6 - 6 x \$800 = \$4,800 Activity 8-10 - 2 x \$500 = \$1,000 Activity 7-8 - 3 x \$900 = \$2,700 Activity 4-7 - 2 x \$950 = \$1,900 Activity 2-4 - 1 x \$1,100 = \$1,100 Direct Cost + Crashing Cost = \$860,000
Total Cost	\$1,034,500	\$1,028,000

6.2 OBDO Solution

The TCT solution is economically beneficial to a contractor since additional compressions will cause total cost increment. However, an owner needs to consider not only the total cost but also the economic benefit. If the owner borrows \$845,500 with 4% annual interest, the interest reimbursement is almost \$100/day, neglecting the time value of money. If future revenue after completion is \$650/day, the opportunity cost is \$750/day. From Table 1, the compression ranges for the three activities 2-3 (\$1,200), 2-5 (\$400), and 2-4 (\$1,100) are 2 days, 4 days, and 3 days respectively (activity 2-4 had been crashed by one day, 3 days are still available). The maximum crashing range for the OBDO compression is only 2 days. This compression, which is processed based on the concept of the OBDO is shown in Fig. 6. ΔC_t is \$2,700-\$2,100=\$600. ΔR_c is \$650. ΔI_c is \$100. ΔZ is thus \$650+\$100-\$600= \$150. For a two days compression, the opportunity income is \$1,500, which is \$300 more than the increased total cost of \$1200 (Table 3). The OBDO compression causes a cost increment but the owner benefit more with the further compression. The crashing ranges of individual activities need to be established because some activities cannot be crashed without limit due to their physical properties. For example, the activity of pouring and curing concrete cannot be crashed without limit. Although extra resources and capital are available, curing of poured concrete takes a fixed minimum number of days and cannot be expedited without limit. Moreover, for simplicity, the time cost relationships of individual activities on the network of this example are all assumed to be linear and all the results are calculated manually. Nevertheless, this is acceptable as the objective of introducing this example is to prove the feasibility and practicability of the proposed OBDO model.

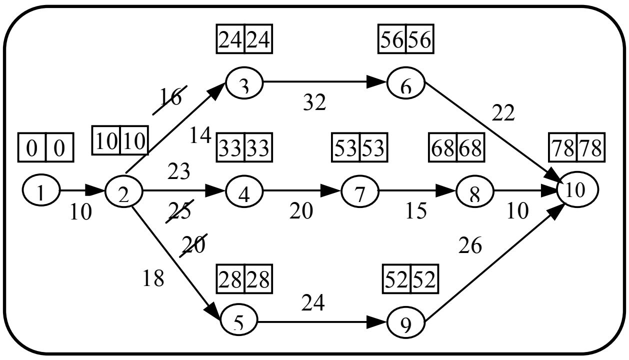

Figure 6. OBDO Solution

Table 3. Normal, compressed and OBDO solutions

Items (1)	**Normal solution** (2)	**TCT solution** (3)	**OBDO solution** (4)
Project Duration	90 days	80 days	78 days
Indirect Cost	$189,000	$168,000	$163,800
Direct Cost	$845,000	$860,000	$865,400
Total Cost	$1,034,500	$1,028,000	$1,029,200
Marginal Revenue + Interest Saving $\Delta O_c = \Delta R_c + \Delta I_c$	0	0	$1,300+$200 = $1,500
Owner's Marginal Benefit $\Delta Z = \Delta O_c - \Delta C_t$			$1,500-$1,200 = $300

7. CONCLUSIONS AND FUTURE WORK

The significance of employing the OBDO model can be summarized as follows:

1. Project owners are the most beneficiary participants from OBDO application. OBDO model incorporates the parameters of interest saving and future revenue into its objective function.
2. OBDO avoids other unpredictable risks due to earlier completion. The development of a large-scale construction project is spread over a long time period during which the risks are difficult to predict. Generally, the longer a project lasts; the more risks the project participants encounter. These risks directly influence the cost, duration and the profitability of the project. Therefore, if the construction completes earlier than originally planned with the best economic benefit, all participants would operate the project with more confidence and certainties, without having to consider the negative influences of these risk factors to project benefit and duration.
3. The schedule and cost from OBDO can be used as an innovative criterion of contractor selection/evaluation. Owners do not have to award contracts to the tenders with the lowest bidding prices, but to the bidders who can complete the project within the desirable schedule with minimum cost increment, maximizing the owner's benefit on both time and cost considerations.

Unlike the traditional TCT problems that are limited in considering a contractor's solutions with minimized cost or duration within the construction phase, OBDO aims to optimize overall economic benefit for owner through a new scheme of schedule compression in a large-scale construction project during its whole lifecycle. Difficulties arise because, for large-scale construction project with hundreds or thousands of activities, in order to maximize the overall economic benefit for an owner, it is impossible to enumerate all possible combinations of activity crashing to identify the optimal decision for schedule compression. It is also impractical to manually calculate the increased total cost and benefits after schedule compressions. Therefore, in the course of future research work, an enhanced OBDO model with integrated optimization algorithm that deals with complex computations are highly desirable to tackle this complicated optimization problem.

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