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Use of optimization techniques in time-cost trade off (TCT) in civil construction: An Overview

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Abstract

Over a year many research had solved construction optimization problems. The techniques used by them varied in nature between mathematical techniques or conventional techniques to heuristic techniques. Over a past 20 years researchers had emphasized on Evolutionary Algorithms (EA) to solve construction optimization problems. Different Evolutionary Algorithm techniques such as Genetic Algorithm (GA), Ant colony method etc, had been used by many researchers to optimize the time-cost of a construction project. In this paper a detailed literature review of different approaches used by researchers to optimize the time-cost of a construction project is going to be highlighted.

Keywords: time-cost trade-off, Algorithms, Genetic Algorithm

Introduction

Time and cost are two main factors in a construction industry; generally are used for planning of a project. To complete the project, it is must to estimate the time and cost of each activity through which the whole duration and total cost of the project can be estimated. Project planning is defined as "a process of choosing the one suitable method and order of activities from all the various ways and sequences in which it could be done, for completion of a project" (Antill and Woodhead 1990). Generally Project planning serve as a foundation for several related functions such as scheduling, cost estimating, project control, quality control, safety management and other function. Planning is different from scheduling, planning is the determination of the timing and sequence of operations or activities in the project and their assembly to give the overall completion time (Mubarak, 2005). Pilcher (1992) gave the objective of planning in construction work, planning is usually completion of a prescribed amount of work within a fixed duration and at a previously estimated cost. In the past time is the unit that received a more attention over the cost. Now to achieve a greater efficiency, the planning of time and cost are very closely linked. Therefore every construction project is subdivided into different elements for network schedules, are called “activities”. An activity is a single work step that have a fixed or definite begin time as well as end time.

Hinze (2004) said that the duration of an activity is the estimated time that will be required to complete a particular activity. Generally, in construction project the unit of time is days and it is assumed that work is performed on a continuous and uniform basis. Time might also be measured in months, week, shifts, or even hours. Activity durations are directly linked with the resources applied (e.g., crew size and equipment) and the productivity of these resources, to complete a particular activity. Logical relationships exist between activities of a project. In a common way the start of some activities depends on the completion of other activities. A concrete wall cannot be started until the forms are up and the reinforcing steel has been tied. In construction project certain activities are independent of one another and can proceed concurrently. Precedence relationships could take the form finish-to-start (FS), start-to-start (SS), and finish-to finish (FF) (Chassiakos and Sakellaropoulos, 2005). Due to these logic relations, the activities of the project can be formed as a network. At first Critical Path Method (CPM) was developed to optimize the organization of complex procedures of an activity network and also to identify critical activities in a network situated at critical path. Activities in the network can be carried out in parallel so that the critical path is the length of the longest path from the start of project to its finish. An activity is said to be critical if there is no difference between its earliest start time and latest finish times (Lin, 2001). Once the duration of all the activities in a project is estimated, the project duration can be calculated with CPM. Generally the project duration is the sum of the durations of all activities on the critical path. As per the contractor’s point of view, various costs associated with a project and its relation is shown in Fig.1 (Pilcher, 1992). This figure shows the main components of the construction cost, company overhead and markup. The estimated cost for a contractor to complete the work is known as the construction cost and it consists of the direct cost to carry out the work and the indirect cost (i.e. site overhead).

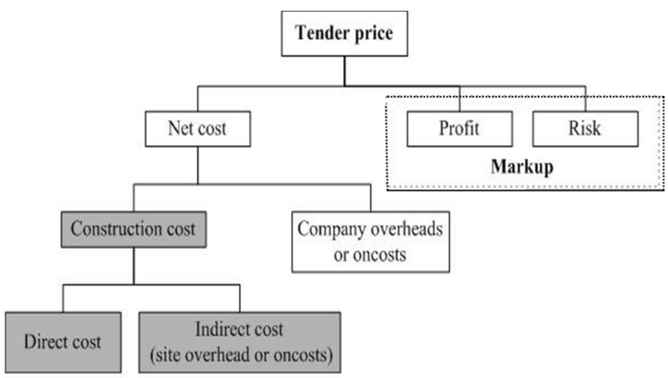

Fig.1. Components of tender price (Pilcher, 1992)

A direct cost represents the costs of the resources used by activities, such as the materials installed, labour, equipments and subcontractor. The costs of materials and the costs of the subcontracted work tend to be relatively fixed or not subject to considerable variation. The biggest variable concerns the costs associated with labour and equipment.

Indirect costs are those cost which are not specifically associated with a particular work item. Site overheads include all the costs needed to operate the site work production activities and cannot be attributed to direct costs. It includes site management and supervision, offices, canteen, storage sheds, cars and other transport like temporary roads and services, and also general labour not assigned to production.

When the trade-off of all the activities is considered in the project then the relationship between project duration and the total construction cost is developed as shown in Fig.2. Direct cost is the summation of all the activities construction cost and indirect cost is the project site overhead. Hence, the total project construction cost can be calculated by adding direct cost to indirect cost. When the duration for the project is reduced, the total cost becomes quite high and as the duration increases, the total cost increase but at a rate that is lower than the daily rate.

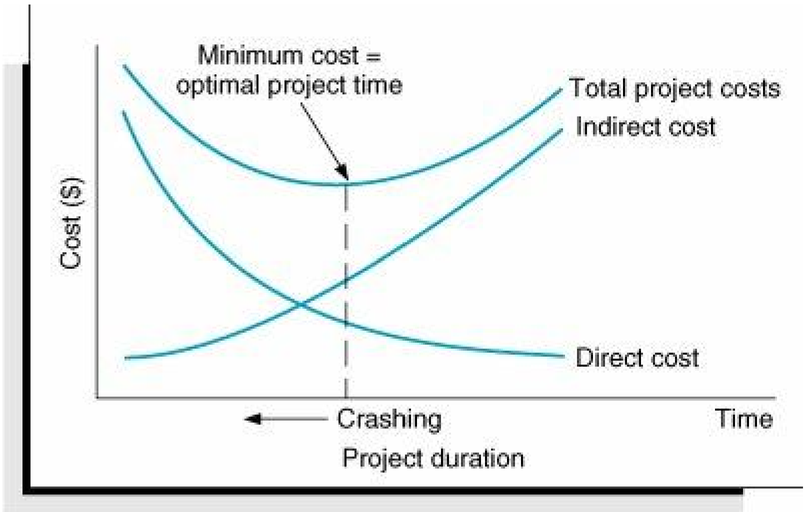

Fig 2: General relationship of project construction cost to duration

Hence this time-cost problems in construction tends to develop a suitable algorithm that can establish an optimize relation between them**.**

Solving TCT problem

A number of methods had been proposed to solve the construction time-cost trade-off problems. These methods can be classified as: mathematical methods, heuristic methods and meta-heuristic methods. Each of these methods is discussed below:

Mathematical methods:

Mathematical programming method convert the Time-Cost Trade-Off problem (TCTP) to mathematical model and utilize linear programming, integer programming and dynamic programming to solve them.

Liu et al(1995) had developed an linear programming (LP) model for optimizing time-cost problem of construction project. The proposed model can be expressed as follow:

$$\text{Minimize} \sum_{i=1}^{n} ci$$

Subject to

$$Si \geq 240,\ i= 1,2,\_\ \_\ \_\ ,n$$

$$Si+Di \leq 24Dmax,\ i=1,\ 2,\_\ \_\ \_,n$$

$$Sa+Da \leq 24Sb, \text{ for each precedence } a \quad b \longrightarrow$$

$$Ci \geq 24MijDi + Bij,\ i= 1,2,\_\ \_\ \_,n,\ j= 1,2,\_\ \_\ \_,0i$$

$$Ci \geq 24C^{min}i, \quad i= 1,2,\_\ \_\ \_,n$$

$$Di \geq 24D^{min}i \quad i=1,2,\_\ \_,n$$

Where Ci = cost of activity i

Si, Di, Oi= start time, duration and number of inequality constraint of activity i respectively

Dmax = maxi. Allowable overall project duration

$C^{Min}i$ and $D^{min}i$ = mini. Cost and duration of activity I respectively

Mij = slop of inequality constraint connecting the adjacent active options Pair

n = total number of all activities

Bij = intercept of cost for option j with respect to activity i

The limitation of this approach is that, the problem needs to be formulated (i.e. the objective function and constraints) , this is time consuming and difficult task for construction planner who don’t have specified mathematical knowledge and background.

Burns et al (1996) had proposed a hybrid optimization approach that is combination of linear programming and integer programming for determining the time-cost trade-off solution of construction scheduling problem. The method is applied in two stages: first stage is used to generate lower bound of the minimum direct curve and in second stage integer programming is used to find the exact solution. The limitation of this method is that it is time consuming and tedious.

Moselhi and El- Rayes (1993) had used a dynamic programming model by introducing a cost variable into the optimization process. The model gives solution in two stages, in first stage model had used time-cost trade-off analysis to determine local minimum condition employed. In second stage it involves a simple scanning and selecting process that ensure to attain an overall minimum state. The disadvantage of this method is that formulation of objective functions and constraints is a time consuming and difficult task.

Meyer and Sheffer (1963) and Petterson and Huber (1974) had solved time-cost trade-off problem considering both linear and discrete relationship between time and cost, by using mixed integer programming. However integer programming requires lot of computational effort once the number of option to complete activity become too complex.

Kallantzis and Lambropoulos (2004) had presented a scheduling method for determining the critical path in linear projects, which takes into account maximum time and distance constraints.

Heuristic methods:

A heuristic methods are based on the past experience of the project planner for problem solving.

Fondhal (1961) had developed an alternative method of CPM to optimize construction project. Fondhal had used circle and connecting line diagram to address the Time-Cost Trade-Off problem. The advantage of method was that it can be solved manually. The disadvantage of this method is that it does not provide a global optimal solution of problem.

Prager (1963) had proposed an model for optimization of time-cost problem for construction project. The limitation of this model is that, it is applicable for problem having a linear relationship between time and cost. For problem having nonlinear relationship between time and cost, it is not applicable.

Siemens (1971) had proposed an algorithm that can reduce the duration of project when the duration of project exceeds its predetermined limit. An advantage of this method is that it could be used to solve time – cost trade- off problems manually without need of computer and it is simpler than some analytical method such as linear programming. The disadvantage of this method is that solution obtained by this method is not guaranteed to be global optimal solution.

Moselhi (1993) had proposed an method for optimizing the total duration of project at mini mum total cost. In this method constraint was scheduled to complete the project on predetermined time. This method was based on ‘direct stiffness method’.

Hegazy et al (2000) had improved a heuristic resource- scheduling solution by introducing multi-skilled resources. The advantage of this method is that it stores and utilizes information about the resource that can be substituted. By using this information less important resource can be used at shortage period in order to reduce project duration and cost.

Zheng et al (2006) used a heuristic method to optimize time-cost problem of construction project. In this method all activities of a project are grouped according to the possible combinations and schedule all the activities in the selected group to minimize the project duration. A heuristic algorithm ranks all alternative combinations of activities and select best one from them, which having minimum project duration. The limitation of this approach is that, it had not considered the effect of reduction in duration to the direct cost or overall cost of the project.

Meta-heuristic methods:

Different meta-heuristic methods had used for time-cost trade-off problem. These methods are: Genetic Algorithm (GA), Ant Colony method etc.

Feng et al(1997) had used a GA to solve construction time-cost trade-off problem using Pareto. This model provides a number of solutions for particular project. The limitation of this approach is that it is only applicable to the finish to start relationship within the activities and it is also unable to deal with limited resources available for a completion of project.

Li and Love (1997) had proposed a model to reduce the computational effort for optimization of problem. They had produced an improved GA model for optimizing time, cost and resources. The disadvantage of a proposed method is that

(1) They consider crash time as continuous variable which can be impractical.

(2) They did not consider resource constrained situation.

Li et al (1999) had considered a non-linear relationship between time and cost to optimize time-cost problem. They had generated a quadratic time-cost curve to formulate the objective function that can be solved by GA. The disadvantage of this method is that the quadratic time-cost relationship was considered by them is not appropriate for more complex project.

Hegazy (1999) had used a GA solver tool in MS project 4.1 to optimize the construction time-cost problem. An advantage of this method is that it considers project deadline, daily incentive, daily liquidated damage and daily indirect cost. Disadvantage of this method is that it is random in nature and require considerable amount of computation time for large network problem.

Leu and Yang (1999**)** had developed a GA based multi-criteria computational optimal model for construction scheduling optimization. In that model multiple attributes decision making method is used to find non dominated solution. The limitation of this approach is that it requires a large computational effort.

Senouci and Eldin (2004) had proposed an augmented lagrangian GA model for construction resource scheduling problem .They had considered several issues such as precedence relationship, total project cost minimization and time-cost trade-off. They had considered linear and non-linear cost duration curve to develop an objective function for minimizing total project cost.

Zheng et al (2005) had used a pareto ranking approach for selection phase of GA. In pareto ranking approach all non-dominated solution are grouped and ranked. The group having a higher rank will have a great chance to survive. This approach overcomes the weakness of roulette wheel method. The limitation of this approach is that, the resources are assumed to be unlimited.

EL-Rayes and Kandil (2005) had developed a GA based approach to solve the highway construction problem. They had also considered a quality of a project as an important factor. Due to the introduction of quality, the traditional time-cost trade-off problem is transformed into a time-cost-quality trade-off problem. The main objective of this approach was to minimize the time and cost of a project and to increase the quality of a project. A number of quality indicators used by them, for each activity to check the quality of a project. They had introduced pareto optimal and Niche comparison rule for GA computation.

Chen and Weng (2009) had developed a two phase GA model to solve a resource scheduling problem for construction project. In first stage, the author had used GA based time-cost trade-off problem to select the schedule for each activity after that a GA based resource scheduling method was used to generate a feasible solution that satisfied the project constraints.

Sedigheh Nader Abedi et al (2011) had proposed a two-phase GA model for optimization of multi-mode resource time-cost trade-off (MRCTCT) problem. In proposed model they were also considered a resource requirement of each activity.

N. Sharsavari Pour et al (2012) had proposed a GA and fuzzy based approach to solve TCT problem. In proposed method they were used Taguchi method to set the parameters in the model. They had considered an uncertainty condition to optimize time-cost of a construction problem.

Laksnminarayanan et al(2010) had considered a risk factor as an important factor in optimization of construction project. An ACO approach was used to solve the time-cost-risk trade-off problem of construction project. On the basis of TCT problem, an objective function associated with each activity was introduced by using a set of quality indicators. The risk associated with construction project was classified and grouped into number of zones base on their importance.

Ng and Zhang (2008) had applied ant colony optimization (ACO) approach to solve TCT problem of construction industry. During the use of ACO approach there is a tendency for premature convergence to occur. The limitation of this approach is that there is no existing criterion for choosing those parameters within the algorithm.

Shrivastava et al (2012) had developed a multi-objective optimization approach for time-cost-quality-quantity problem of construction project based on ACO approach. The objective functions were obtained by quantifying the duration, total cost and quality of a project. The limitation of this approach is that a parameter chosen by them is based on a random selection.

GA working principle and its use:

GA belongs to the larger class of evolutionary algorithms (EA) that solves optimization problems using techniques based on natural evolution. Other members of EA include genetic programming, evolutionary programming and evolution strategy. A GA is a random searching algorithm based on the mechanism of natural selection and survival of the fittest. The three most important phases involved in GA are selection, crossover and mutation (Fig. 3). To utilize GA, all the decision variables, for example options for each construction activities, are encoded into a string called a chromosome whose genes are represented by binary digits, integers or real numbers. Then, an initial population is chosen randomly and each chromosome's fitness is evaluated with regard to the objective function. According to the fitness, a selection method is employed and a candidate population is created for crossover that allows information exchanges between parents to generate new offspring. In the mutation phase, genes are altered on some randomly chosen locus to eliminate the premature problem caused in the crossover. Then, a new population is generated for the next round iteration. The GA is an efficient global parallel searching algorithm that can accumulate information from the searching space and obtain an optimal or suboptimal solution adaptively.

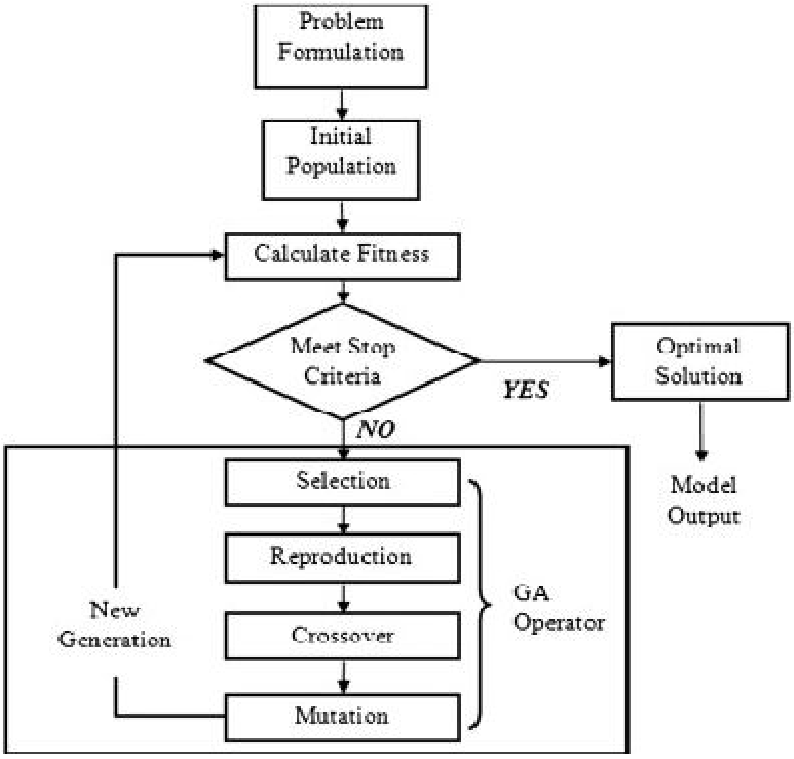

FIG.3. Flowchart Showing Genetic Algorithm Process

Case study :

To explain the working process as well as suitability of GA we are preferring a case study of a project of seven activities driven by Sultana Parveen and Surajit Kumar Saha (2012).

A project of seven activities is taken as an example which was derived by Zang, Ng and Kumarswamy (2004). Table 1 shows available activity options and corresponding durations and costs. This study was developed including the resources-time trade-off as input, so that the cost of each option was taken as resources to fit the case into the proposed model. Indirect cost rate was $1500/day.

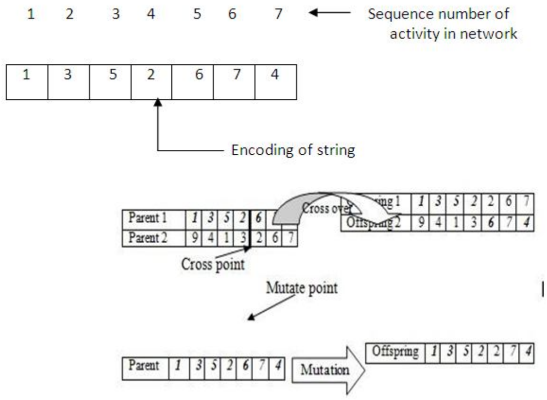

Fig 4 - Mechanism of GA (Sultana Parveen et al 2012)

Table 1 Option for seven activities

activity number	precedent number	option	direct cost ($)
1		1	23000
		2	18000
		3	12000
2	1	1	3000
		2	2400
		3	1800
		4	1500
		5	1000
3	1	1	4500
		2	4000
		3	3200
4	1	1	45000
		2	35000
		3	30000
5	2,3	1	20000
		2	17500
		3	15000
		4	10000
6	4	1	40000
		2	32000
		3	18000
7	5,6	1	30000
		2	24000
		3	22000

Table 2 – Optimam solution of Time-Cost Trade - Off problem by using GA Technique with the help of Matlab software

Model	Optimal Solution								
	Time (days)	Cost ($)	Duration of activity (Day)						
Gen and Cheng (2000)	79	2,56,400	24	18	15	16	22	14	15
MAWA (Zeng et al, 2004)	66	2,36,500	15	15	15	20	28	18	9
The new model	60	233500	14	15	15	12	22	24	9
	62	233000	14	15	15	20	24	18	9
	63	225500	14	15	15	16	24	24	9
	67	224000	14	15	15	20	28	24	9
	68	220500	14	15	15	20	30	24	9

The final solution obtained by Gen and Cheng(2000) model and MAWA model (Zheng et al,2004) shown in table2 respectively were not global optimal solution. The new model shows a pareto optimal solution and best optimal solution i.e. project time= 60 days and cost= 2,33,500$.

Conclusion

Generally construction time-cost trade off problem (TCTP) is large scale optimization problem. A number of methodologies that had applied to solve the time–cost optimization problem which can be classified into three categories: mathematical methods, heuristic methods and meta-heuristic methods. To solve construction time-cost trade-off problem by using mathematical method, the problem needs to be formulated (i.e. the objective function and constraints). This is a time-consuming and difficult task for construction planners who do not have the specified mathematical knowledge and background.

The advantage of heuristic methods is their simplicity and it can be solved by manually without need of computer. The well-known heuristic methods are Fondahl's method, Structural model method, Siemens approximation method and structural stiffness method. Due to its simplicity and efficiency, Fondahl's method had adopted by many commercial project scheduling software. The limitation of heuristic method is that, most heuristic methods are problem dependent which makes them difficult to apply to other projects equivalently. However, most of the current heuristic methods focus on single project scheduling. Only a few of them can deal with multiple projects scheduling problem.

The most commonly adopted meta-heuristic method is the GA for construction time-cost optimization problems. By introducing concept of Pareto optimality, a GA can provide a numbers of a solution for the decision maker. Generally GA based on the random searching mechanism, so that it could solve a variety of optimization problems by searching a larger solution space. Selection of the fitness function is difficult task for GA computation.

An improper selection of fitness function may cause the algorithm to be trapped into local optimal. Genetic algorithm cannot deal with a problem having a dynamic data. In genetic algorithm model, the size of the initial population is also important for the operation of the algorithm. With the increase in population computational effort may also increase as well as small population does not provide an optimal solution. Due to its random searching mechanism, genetic algorithm can always provide a better solution compared with the other solutions.

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