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DECISION-MAKING PROCESS TECHNIQUES USED IN THE OPTIMIZATION OF CONSTRUCTION PROJECTS

ABSTRACT

It is desirable that the construction projects can be completed in the most appropriate manner at the desired time, cost or other purposes. If any of these requests are solely aimed, the appropriate project parameters can be determined and the results such as the optimal time or cost can be determined after an optimization process. If more than one goal is to be achieved at the same time, the decision making process becomes more difficult. In this case, rather than a single final result, multiple results can be obtained. A number of techniques are used to optimize both time and cost. In this study, the techniques proposed for this purpose in the literature have been examined and some of these techniques have been applied to the construction projects considered as time-cost problem. Also, the TLBO algorithm, popular in recent years, has been the preferred in the solution of the multi-objective optimization problem. Construction project business activities which are taken into account as a time-cost problem in the literature are examined as numerical examples. A computer program is developed to realize the time-cost trade-off problem by using MATLAB.

Keywords*:* Optimization, Construction Project, Decision-Making, Construction, MATLAB

1. INTRODUCTION

In the case of multiple purposes such as time and cost, multi-objective optimization techniques is preferred to solve construction projects. In single-objective optimization problem, the optimal solution is generally achieved, but it is not simple for the multi-objective optimization problems. Instead of a single solution, there are alternative solutions in the multi-objective problems. These solutions are generally defined as Pareto-optimal solutions. It is difficult to decide which solution is better than the other one in the large solution space. The total time of a construction project depends on the skill of the time estimator, applied technology, the financial plan and many other factors. The total cost of the same project can be found as a function of the time determined by manual or by using computer software. The aim is to obtain a minimum time and a minimum cost in a time-cost trade off problems. After the time-cost relationship was firstly introduced by Bromilow in 1969 [1], many researchers presented similar studies for civil engineering projects [2]. If the variables of the time-cost trade-off problem are too many, the optimization algorithms and multi-objective optimization techniques can be used to found an optimum time and cost for a construction project. In this study, among the different algorithms given in literature, the teaching-learning-based optimization (TLBO)

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algorithm is applied to the time-cost trade-off problem as an optimization algorithm. Also, to make a decision between total cost and the total time of the construction project, the Modified Adaptive Weighting Method (MAWA) and Non-dominated Sorting-II (NDS-II) technique is used to find Pareto solution of the selected problem.

2. RESEARCH SIGNIFICANCE

There are many approaches to decide the optimal solution for the objective function of the optimization problem. Especially, in the case of multi-objective optimization problem which have more than one objective function such as time and cost to decide optimal solution will not be easy. To overcome this difficulty, the Non-dominated Sorting-II (NDS-II) technique is preferred in this study. Also, the teaching-learning-based optimization (TLBO) algorithm is used as an optimization algorithm for the time-cost trade of problem in this paper. So, this study will be helpful to the researcher related to the optimization and time-cost trade of problem.

3. TIME-COST TRADE-OFF PROBLEM IN CONSTRUCTION PROJECT

There are two objectives to be minimized in the time-cost trade-off (TCT) problems. These are project time and cost. The general form of the cost function can be given by following equation.

$$C=\sum_{i=1}^{l}\sum_{j=1}^{r}C_{d_{ij}}+C_{id} \tag{1}$$

Where, C is the total project cost, C_{dij} the direct cost of resources type j at activity i, C_{id} the indirect cost of project, r total number of resource types and l is the total number of activity.

The indirect cost C_{id} is a function of the total project time and desired project time.

$$C_{id}=T.C_L+D.(T-T_a) \tag{2}$$

$$D=\begin{cases}C_p, & T>T_a\\ 0, & T\le T_a\end{cases} \tag{3}$$

In Eq.(3), C_L is the indirect cost rate, Cp the delay fine rate for unit time delay and desired project time Ta. The total project time T is given by equation (4);

$$T=\max\{EST_i+t_i\} \qquad i=1,2,...l \tag{4}$$

Where, EST_i the earliest starting time of activity i. The detailed information can be found from the studies related to the time-cost trade-off problem such as [3]. In this study, to calculate the total project time the critical path method (CPM) is used.

4. TLBO ALGORITHM WITH MAWA AND NDS-II

4.1. TLBO Algorithm

As a meta-heuristic algorithm, TLBO algorithm which mimics teaching-learning process in a class between the teacher and the students (learners) is developed by Rao et al. [4] and applied first for solving the mechanical design optimization problems. To implement the TLBO two key steps known as “Teaching Phase” and “Learning Phase” must be performed, respectively. The “Teaching Phase” produces a random ordered state of points called learners within the search space. Then a point is considered as the teacher, who is highly learned person and shares his or her knowledge with the learners. However, the learning process is represented by interaction between each learner in the “Learning Phase”. After a number of sequential Teaching-Learning cycles, the distribution of the randomness within the search space becomes smaller and smaller about to point considering as teacher, which means that knowledge level of the whole class is close to teacher's level and the algorithm converges to a solution. The general flow chart of TLBO is given in Figure 1.

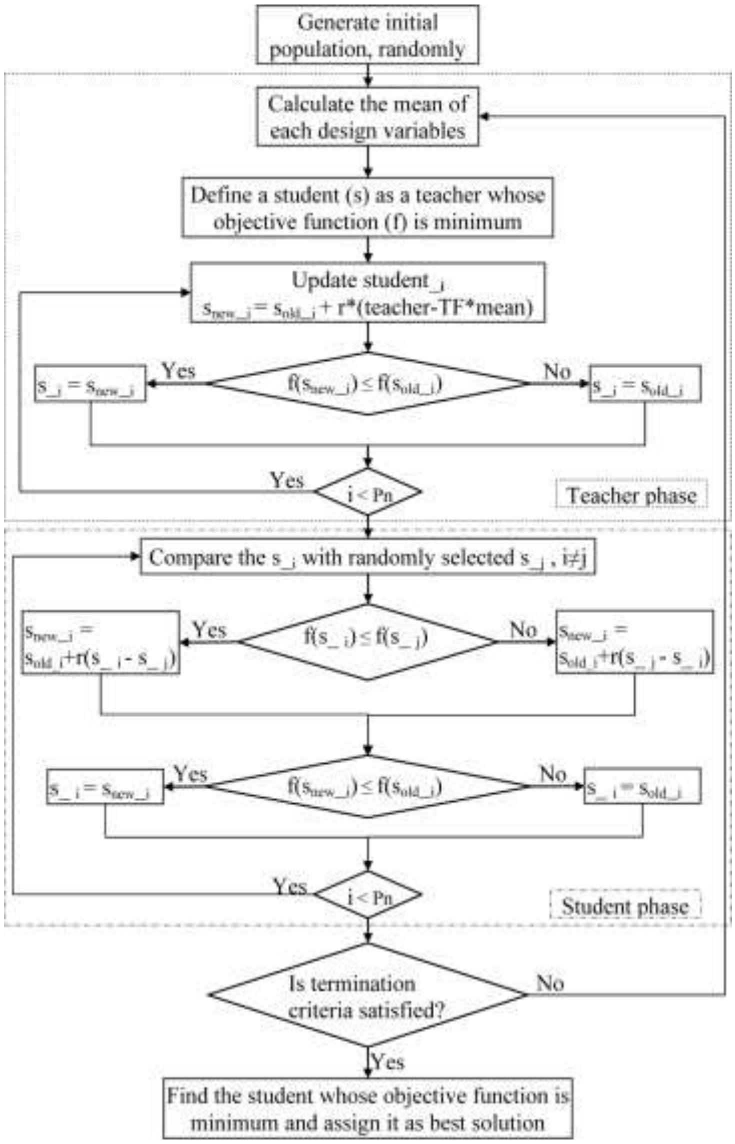

Fig. 1. Flow Chart for TLBO

In this figure, the abbreviation TF, r and Pn are the teaching factor, random number and the population size, respectively. The detailed knowledge about this algorithm can be found from the studies Rao et al. [4] and Dede [5]. In this study, the teaching-learning-based optimization is adopted to find pareto solution by using Modified Adaptive Weighting Method (MAWA) and Non-dominated Sorting-II (NDS-II).

4.2. Modified Adaptive Weighted Approach (MAWA)

In the modified adaptive weighted approach [6], the following four conditions are recognized to use an alternative fitness function instead of time or cost [7]. This alternative fitness functions combines the time function and the cost function calculated for the time-cost trade-off problem in the construction project. For this approach the Matlab-codes are given in Figure 2.

Where vc is a value for the criterion of cost, vt is a value for the criterion of time, v is value for the project, wc is adaptive weight for the criterion of cost, and wt is adaptive weight for the criterion of time. The alternative fitness formula in MAWA is calculated as,

```
if   Zc_min~=Zc_max && Zt_min~=Zt_max
     vc= Zc_min/(Zc_max-Zc_min);
     vt= Zt_min/(Zt_max-Zt_min);
     v= vc+vt;
     wt =vt/v;
     wc= vc/v;
else if  Zc_min==Zc_max && Zt_min==Zt_max
     wt=0.5;
     wc=0.5;
else if  Zc_min~=Zc_max && Zt_min==Zt_max
     wt=0.9;
     wc=0.1;
else if  Zc_min==Zc_max && Zt_min~=Zt_max
     wt=0.1;
     wc=0.9;
end
```

Figure 2. Matlab codes for MAWA

$$f(X) = w_t \frac{Z_t - Z_t^{\min} + \gamma}{Z_t^{\max} - Z_t^{\min} + \gamma} + w_c \frac{Z_c - Z_c^{\min} + \gamma}{Z_c^{\max} - Z_c^{\min} + \gamma} \quad (5)$$

where X is sequence number of the solution of a cycle; Zc, Zt represent the value of the objective of cost and time of the Xth solution respectively; γ is a uniformly distributed random number between 0 and 1, which is introduced here to avoid zero or invalid value of the integrated value [7]. After calculation of alternative function, the fitness function given in the Fig. 1 for the basic TLBO algorithm is replaced with this new function.

4.3. Nondominated Sorting- II (NDS-II)

The other approach is the Nondominated Sorting- II. When the population in initialized the population is sorted based on non-domination into each front. The first front being completely non-dominant set in the current population and the second front being dominated by the individuals in the first front only and the front goes so on. Each individual in the each front are assigned rank (fitness) values or based on front in which they belong to. Individuals in first front are given a fitness value of 1 and individuals in second are assigned fitness value as 2 and so on [8]. The Matlab codes are given in the Figure 3. Individuals are selected from the current population based on the rank value of each individual. If the rank values of the individuals are the same, another criteria called crowding distance are calculated for the sorting the individuals. The crowding distance is a measure of how close an individual is to its neighbors [8]. The Matlab codes are given in the Figure 4.

```
T=[];
t=0;
for k=1:nPop
    empty_individual.Dominated=0;
    pop=repmat(empty_individual,nPop,1);
    t=t+1;
    R{t}=[];
    F=setxor(T,1:nPop);
    for i=1:numel(F)
        for j=i+1:numel(F)
            p=f(F(i),:);
            q=f(F(j),:);
            if all(p<=q) && any(p<q);
                 pop(F(j)).Dominated=1;
            end
            if all(q<=p) && any(q<p);
                pop(F(i)).Dominated=1;
            end
        end
        if pop(F(i)).Dominated==0
            R{t}=[R{t} F(i)];
        end
    end
    if numel(R{t})==0
        R{t}=F;
        break
    end
    T=[T R{t}];
    if numel(T)==nPop
        break
    end
end
for i=1:numel(R)
    pop_rank(R{i})=i;
end
```

Figure 3. Matlab codes for NDS-II

```
e=0.0000001;% to avoid singularity
nPop=size(f,1);
pop_CrowdingDistance=zeros(nPop,1);
 for i=1:numel(R)
    pop_cd=zeros(numel(R{i}),2);
     for j=1:size(f,2)
        [fsort, findex]=sort(f(R{i},j));
         pop_cd(findex(1),j)=inf;
         pop_cd(findex(end),j)=inf;
          for k=2:numel(R{i})-1
             pop_cd(findex(k),j)=abs(fsort(k+1)-fsort(k-
1))/abs(fsort(1)-fsort(end)+ e);
         end
    end
    pop_CrowdingDistance([R{i}'])=sum(pop_cd,2);
end
```

Figure 4. Matlab codes for crowding distance in NDS-II

An individual is selected in the rank is lesser than the other or if crowding distance is greater than the other 1. The selection is based on rank and the on crowding distance on the last front. The population in the "Teaching Phase" and "Learning Phase" of the TLBO algorithm is changed with the population obtained from the function called Nondominated Sorting- II. To demonstrate the using of NDS-II with the TLBO algorithm the following figure are given.

Create number of initial population
Keep the population in archive

Update population based on teacher phase
Combine the updated and archived population
Apply the NDS-II to the combined population
Select the best solutions up to half of the combined population
Keep the selected population in the archive

Teacher Phase

Update population based on learner phase
Combine the updated and archived population
Apply the NDS-II to the combined population
Select the best solutions up to half of the combined population
Keep the selected population in the archive

Learner Phase

Figure 5. Using NDS-II with the TLBO algorithm

5. NUMERICAL EXAMPLE

A project of seven activities is considered as an example to show the application of the TLBO algorithm and the multi-objective approach MAWA and NDS-II. The configuration of this project is given in the Figure 5 and the optional days and direct cost for the activity of the project are given in the Table 1. Indirect cost rate was $1500/day [3].

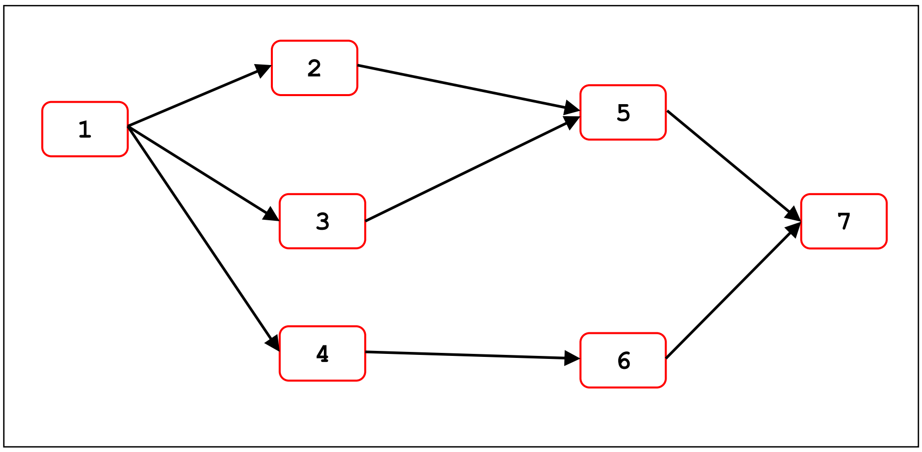

Figure 5. Configuration of seven activity project

Table 1. Options for seven activity example

Activity Number	Precedent Activity	Duration (Days)					Direct Cost ($)				
1	-	14	20	24			23000	18000	12000		
2	1	15	18	20	23	25	3000	2400	1800	1500	1000
3	1	15	22	33			4500	4000	3200		
4	1	12	16	20			45000	35000	30000		
5	2, 3	22	24	28	30		20000	17500	15000	10000	
6	4	14	28	24			40000	32000	18000		
7	5, 6	9	15	18			30000	24000	22000		

The pareto solutions obtained from this study are given in the Table 2 by comparing the other results. Also, the results are given in the Figure 6 and the Figure 7 for the MAWA and NDS-II, respectively. As seen from these figures, the duration of the project can be maximum while the cost is minimum.

6. CONSLUSIONS

The TLBO algorithm is modified for the multi-objective time-cost trade-off problem to minimize both project time and cost in the construction project. The MAWA and NDS-II approach are used in the developed computer programs to realize the multi-objective optimization problem. By the help of this developed program, the pareto solutions for the construction projects are obtained. The results obtained from this study are compared the results given by the other researchers.

Table 2. Options for seven activity example

		Pareto Solutions								
		Time (Day)	Cost ($)	Duration of Activity (Day)						
This Study	TLBO-MAWA	73	228000	20	15	15	20	28	24	9
		68	220500	14	15	15	20	30	24	9
		60	245500	14	15	15	16	22	14	9
		60	233500	14	15	15	12	22	24	9
		67	225900	14	18	15	20	24	24	9
	TLBO-NDS-II	67	230300	14	20	15	16	24	24	9
		60	233500	14	15	15	12	22	24	9
		68	220500	14	15	15	20	30	24	9
		70	231500	14	25	15	20	22	24	9
		63	227400	14	18	15	16	22	24	9
Zheng et al.[9]		66	236500	14	15	15	20	28	18	9
Parveen and Saha[3]		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
Gem and Cheng[10]		79	256400	24	18	15	16	22	14	15

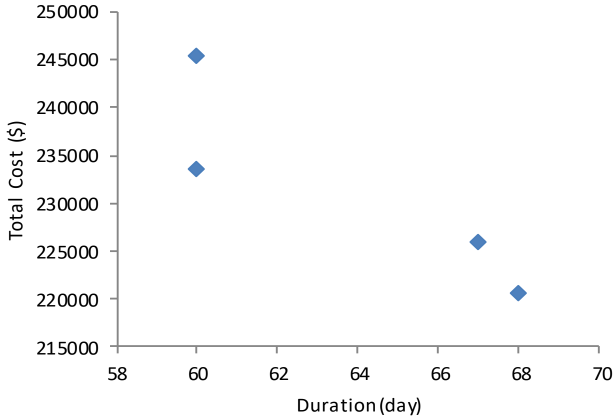

Figure 6. Pareto solutions obtained from the MAWA approach

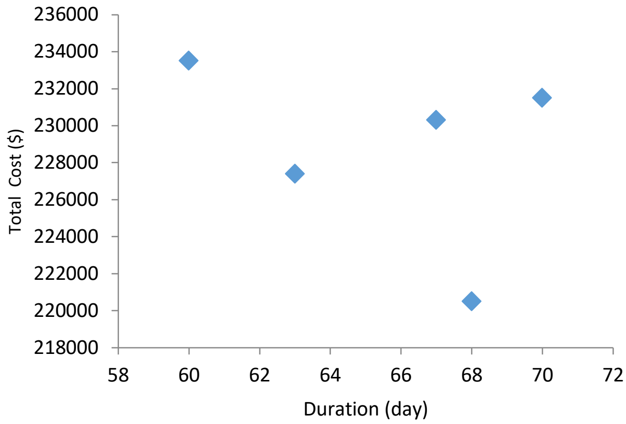

Figure 7. Pareto solutions obtained from the NDS-II approach

NOTICE

This study was presented as an oral presentation at the International Conference on Advanced Engineering Technologies (ICADET) in Bayburt between 21-23 September 2017.

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