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MULTIOBJECTIVE OPTIMIZATION: TIME-COST APPLICATION IN CONSTRUCTION

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Abstract *In a construction project, there are two main factors, such as project duration and project cost. These are depended to each other. The activity duration is a function of resources (i.e. crew size, equipments and materials) availability. On the other hand, resources demand direct costs. Therefore, the relationship between project time and direct cost of each activity is a monotonously decreasing curve. It means if activity duration is compressed then that leads to an increase in resources and so that direct costs. But, project indirect costs increase with the project duration. In general, for a project, the total cost is the sum of direct and indirect costs and exists an optimum duration for the least cost. Hence, relationship between project time and cost is trade-off. The main purposes of this study is to incorporate both the duration time and cost into the objective function and to develop an efficient heuristic search scheduling rule using a genetic algorithm.*

1. INTRODUCTION AND BACKGROUND

In today´s market-driven economy, the ability to minimize the time and/or cost of a project could determine the profitability and even the survival of a construction company. The increasing acceptance of alternative tenders and different project delivery systems, such as design and build, management contracting, build-operate-transfer, partnering, etc., allows greater flexibility in construction duration. This also means that both construction time and cost should be considered concomitantly at the estimation and planning and stages [2].

Several approaches to solve the time-cost optimization (TCO) problem have been proposed in the last years: mathematical, heuristic and search methods.

Several mathematical models such as linear programming (Hendrickson and Au [5]; Pagnoni [2]), integer programming, or dynamic programming (Robinson [9]; P. De et al.

[24]) and LP/IP hybrid (Liu et al. [21]; Burns et al. [27]) and Meyer and Shaffer [29] use mixed integer programming. However, for large number of activity in network and complex problem, integer programming needs a lot of computation effort (Feng et al. [7]).

Heuristic algorithms are not considered to be in the category of optimization methods. They are algorithms developed to find an acceptable near optimum solution. Heuristic methods are usually algorithms easy to understand which can be applied to larger problems and typically provide acceptable solutions (Hegazy [28]). However, they have lack mathematical consistency and accuracy and are specific to certain instances of the problem (Fondahl [19]; Siemens [23]) are some of the research studies that have utilized heuristic methods for solving TCO problems.

Some researchers have tried to introduce evolutionary algorithms to find global optima such as genetic algorithm (GA) (Feng et al. [7]; Gen and Cheng [22]; Zheng et al. [11]; Zheng and Ng [10] and Mendes [18]) the particle swarm optimization algorithm (Yang [11]), ant colony optimization (ACO) (Xiong and Kuang [30]; Ng and Zhang [25]; Afshar et al. [1]) and harmony search (HS) (Geem [32]).

2. MULTIOBJECTIVE OPTIMIZATION

This study uses the objective function proposed by Gen and Cheng [22] but with alternatively values by Mendes [18]:

$Z_c^{\max}$ = maximal value for total cost in the current chromosome;

$Z_t^{\max}$ = maximal value for time in the current chromosome;

$Z_c^{\min}$ = minimal value for total cost in the initial population;

$Z_t^{\min}$ = minimal value for time in the initial population;

Z_c = represents the total cost of the x^{th} solution in current chromosome;

Z_t = represents the time of the x^{th} solution in current chromosome.

3. APPROACH

The approach presented in this paper is based on a genetic algorithm to perform its optimization process. The approach combines a genetic algorithm, a schedule generation scheme and a local search procedure (called Random Key Variant for Time-Cost Optimization). The genetic algorithm is responsible for evolving the chromosomes which represent the priorities of the activities [18].

For each chromosome the following four phases are applied:

1) *Transition parameters* - this phase is responsible for the process transition between first level and second level;
2) *Schedule parameters* - this phase is responsible for transforming the chromosome supplied by the genetic algorithm into the priorities of the activities and delay

time;
3) *Schedule generation* - this phase makes use of the priorities and the delay time and constructs schedules;
4) *Schedule improvement* - this phase makes use of a local search procedure to improve the solution obtained in the schedule generation phase.

4. GENETIC ALGORITHMS

The Genetic Algorithms (GAs) are search algorithms which are based on the mechanics of natural selection and genetics to search through decision space for optimal solutions.

The GA based-approach uses a random key alphabet U (0, 1) and an evolutionary strategy identical to the one proposed by Goldberg [8].

Each chromosome represents a solution to the problem and it is encoded as a vector of random keys (random numbers). Each solution encoded as chromosome is made of $mn+n$ genes where n is the number of activities and m is the number of execution modes, see Figure 1.

Activity 1	Mode 1	Gene $_{11}$
	Mode 2	Gene $_{12}$
	…	…
	Mode m	Gene $_{1m}$
	Delay 1	Gene $_{1m+1}$
Activity 2	Mode 1	Gene $_{21}$
	Mode 2	Gene $_{22}$
	…	…
	Mode m	Gene $_{2m}$
	Delay 2	Gene $_{2m+1}$
…		…
Activity n	Mode 1	Gene $_{n1}$
	Mode 2	Gene $_{n2}$
	…	…
	Mode m	Gene $_{nm}$
	Delay n	Gene $_{nm+1}$

Figure 1. Chromosome example (adapted from Mendes ???).

5. NUMERICAL EXPERIMENTS

In order to compare the proposed RKV-TCO (Random Key Variant for Time-Cost Optimization) approach, a case study of seven activities proposed initially by Liu et al. [21] was used.

A project of seven activities proposed initially by Liu et al. [21] and fitted by Zheng et al. [11] is presented in Table 1 with available activity options and corresponding durations and costs. Indirect cost rate was $1500/day.

Activity description	Activity number	Precedent activity	Option/ Mode	Duration (days)	Direct cost ($)
Site preparation	1	-	1	14	23,000
			2	20	18,000
			3	24	12,000
Forms and rebar	2	1	1	15	3,000
			2	18	2,400
			3	20	1,800
			4	23	1,500
			5	25	1,000
Excavation	3	1	1	15	4,500
			2	22	4,000
			3	33	3,200
Precast concrete girder	4	1	1	12	45,000
			2	16	35,000
			3	20	30,000
Pour foundation and piers	5	2, 3	1	22	20,000
			2	24	17,500
			3	28	15,000
			4	30	10,000
Deliver PC girders	6	4	1	14	40,000
			2	18	32,000
			3	24	18,000
Erect girders	7	5, 6	1	9	30,000
			2	15	24,000
			3	18	22,000

Table 1. Case study 1 (adapted from Liu et al. [21]).

The robustness of the new proposed model RKV-TCO in the deterministic situation was compared with two other previous models:

- Gen and Cheng [22] using GC approach;
- Zheng et al. [11] using MAWA with a GA-based approach.

The results of RKV-TCO approach are presented in Table 2. The Table 2 shows the values of time and cost for the better generations with Gen and Cheng [22] and Zheng et al. [11] approaches. The algorithm RKV-TCO obtains in the third generation a better solution than the works mentioned above. So, the RKV-TCO ends with project time = 63 days and cost =$225,500 in Table 2.

Additionally we can also state that the RKV-TCO approach produces high-quality solutions quickly once needed only 5 seconds to complete 50 generations.

Approaches	Best generation number	Criteria		Calculation Time
		Time	Cost ($)	
Gen and Cheng [22]	5	79	256,400	Not reported
Zheng et al. [11]	5	66	236,500	Not reported
This paper	2	63	225,500	5 (two) seconds for 50 generations

Table 2. Experimental results.

A second case of study is a project of eighteen activities originally introduced by Feng et al. [7]. The activity relationships for the model project consisting of 18 activities and the three modes of construction for each activity and their associated time and cost are presented in Table 3. Indirect cost rate was $1000/day.

Activity number	Precedent activity	Option/ Mode 1		Option/ Mode 2		Option/ Mode 3	
		Duration (days)	Direct cost ($)	Duration (days)	Direct cost ($)	Duration (days)	Direct cost ($)
1	-	24	1,200	21	1,500	14	2,400
2	-	25	1,000	23	1,500	15	3,000
3	-	33	3,200	33	3,200	15	4,500
4	-	20	30,000	20	30,000	12	45,000
5	1	30	10,000	30	10,000	22	20,000
6	1	24	18,000	24	18,000	14	40,000
7	5	18	22,000	18	22,000	9	30,000
8	6	24	120	21	208	14	220
9	6	25	100	23	150	15	300
10	2, 6	33	320	33	320	15	450
11	7, 8	20	300	20	300	12	450
12	5, 9, 10	30	1,000	30	1,000	22	2,000
13	3	24	1,800	24	1,800	14	4,000
14	4, 10	18	2,200	18	2,200	9	3,000
15	12	16	3,500	16	3,500	12	4,500
16	13, 14	30	1,000	28	1,500	20	3,000
17	11, 14, 15	24	1,800	24	1,800	14	4,000
18	16, 17	18	2,200	18	2,200	9	3,000

Table 3. Case study 2 (adapted from Feng et al. [7]).

The Table 4 shows the results for several mathematical and evolutionary-based methods. The algorithm RKV-TCO obtains better solution than the other GA-based approaches. Furthermore, the algorithm RKV-TCO reaches the optimal solution quickly, i.e., in five seconds.

Approaches	**Criteria**		**Calculation Time**
	Time	**Cost ($)**	
Optimal Solution	110	216,270	-
Excel Solver*	110	254,620	2 minutes
Risk Solver Platform Standard SLGRG Nonlinear*	110	216,270	1.5 minutes
Risk Solver Platform Standard Large-scale GRG Solver*	110	216,270	1.5 minutes
TCT Optimization Using Evolver (includes an evolutionary engine)*	110	238,070	30 minutes
Risk Solver Platform Standard Evolutionary Solver*	110	275,320	18 minutes
Optimization Results using CPLEX CP Optimizer*	110	216,270	9 minutes
IBM ILOG Optimization Studio*	110	216,270	9 minutes
This paper (RKV-TCO)	110	216,270	5 (five) seconds for 50 generations

* Reported by Golzarpoor [3]

Table 4. Experimental results.

6. CONCLUSIONS

A GA based-approach to solving the time-cost optimization problem has been proposed. The project activities have various construction modes, which reflect different ways of performing the activity, each mode having a different impact on the duration and cost of the project. The chromosome representation of the problem is based on random keys. The schedules are constructed using a priority rule in which the priorities are defined by the genetic algorithm. The present approach provides an attractive alternative for the solution of the construction multi-objective optimization problems.

Further research can be extended to more construction project problems to reinforce the results obtained namely expanding the optimization model to consider resource allocation and resource levelling constraints and expanding the number of modes of construction for each activity to turn a more complicated optimization problem.

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