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Procedia Engineering 153 (2016) 595 – 598

Procedia Engineering

www.elsevier.com/locate/procedia

XXV Polish – Russian – Slovak Seminar "Theoretical Foundation of Civil Engineering"

Construction projects' indicators improvement using selected metaheuristic algorithms

Jerzy Rosłon[a]*, Jacek Zawistowski[b]

[a]*Warsaw University of Technology, Faculty of Civil Engineering, al. Armii Ludowej 16, 00-637 Warsaw, Poland*
[b]*Polish Association of Building Managers, ul. Powązkowska 44c 01-797 Warsaw, Poland*

Abstract

In this paper authors present methods currently used in construction for scheduling and tasks sequencing. Authors present sample construction problem. Basing on the example, authors compare selected metaheuristic algorithms (genetic algorithm and tabu search) in terms of construction projects' indicators improvement. The outcomes are analyzed and discussed. The conclusions of the paper might also be used as a guidelines for implementation of presented methods in construction companies.

Peer-review under responsibility of the organizing committee of the XXV Polish – Russian – Slovak Seminar "Theoretical Foundation of Civil Engineering".

Keywords: genetic algorithm; tabu search; construction; optimization; scheduling; sequencing, Monte Carlo simulation

1. Introduction

Construction project (just like any other project) is a unique undertaking or endeavor to be accomplished that can be divided into individual subtasks or activities each of which requires time and scarce resources for its completion. The scheduling in its basic form is a process of finding such start dates of tasks that pre-set resource and precedence constraints are satisfied and at the same time an objective function is optimized (i.e. duration minimization, NPV maximization) [14]. Although the general guidelines for scheduling are similar for different disciplines, one always

* Corresponding author. Tel.: +48 22 234 65 15; fax: +48 22 825 74 15.
E-mail address: j.roslon@il.pw.edu.pl

Peer-review under responsibility of the organizing committee of the XXV Polish – Russian – Slovak Seminar "Theoretical Foundation of Civil Engineering".
doi:10.1016/j.proeng.2016.08.198

has to carefully consider specific parameters of the analyzed problem. It is especially important while dealing with construction projects, which are characterized by uniqueness of technology, location, size, availability of resources, etc. [7], [9], [15].

2. Literature study

Schedule optimization methods can be classified into three methods: *mathematical*, *heuristic* and *metaheuristic* [16], [17]. Among the mathematical methods are e.g. linear programming (LP), dynamic programming (DP) (these methods can be useful for finding the global optimum, however, suffer from some drawbacks – discrete decision variables and the exponential increase in the number of solutions as the number of decision variables increases), Branch and Bound method (effective method, however, requiring high skill of expertise and proper restrictions setup).

The heuristic methods include priority rule-based heuristics [8]. These methods are fairly easy to use, however their use might be slightly problematic when it comes to more complicated schedules. The use of heuristic methods does not guarantee finding the optimal solution of the given problem.

The tasks sequencing problem in construction is far more complicated than in other disciplines (i.e. production processes). It is caused by the uniqueness of each construction project (in terms of technology, location, size, availability of resources, etc.) [7], [9], [15]. Various authors are trying to implement different models which will resemble (to some extent) realistic constraints and complicated characteristics of the problems (different objective functions, criteria, financing models, hybrid algorithms, nondeterministic data, etc.) [2], [11], [6], [10], [12]. Practical problems in construction can be easily qualified as NP-hard (non-deterministic polynomial-time hard) problems. The time needed for solving these problems grows exponentially with the increase the problem's size [5]. That is why mathematical and heuristic methods do not allow for finding solutions of complicated construction problems in acceptable time [7]. For the same reasons metaheuristic algorithms seem to be the most appropriate measures for scheduling and task sequencing [13].

Widely analyzed metaheuristic methods include: *Particle Swarm Optimization* (PSO), *Ant Colony Optimization* (ACO), *Genetic Algorithms* (GA), *Simulated Annealing* (SA), *Tabu Search* (TS). These algorithms do not guarantee finding the optimal solution of the given problem and their results are subject to input parameters. However they are very useful when it comes to solving NP-hard problems, because they allow for finding suboptimal solutions in acceptable time.

3. Practical application

3.1. General assumptions

Authors decided to verify (with the use of commonly available software) possibility of using GA and TS algorithms by a contractor. To achieve that goal, a model of construction project was created, with both deterministic and stochastic parameters. Also, main optimization criterion was selected: reducing (minimizing) maximum monthly cash flow (CFmax). This criterion is rather rarely used in the literature due to the fact it is hard to predict, nevertheless it is a very important factor for a construction contractor. Constraints used in this example are:

- WB (work breaks)– workers teams should not be stopped for less than 1 working week (constraint important due to an option of moving workers between construction sites operated by the contractor. Shorter periods of work on one site could influence efficiency due to adaptation time of workers to a new workplace.)
- ME (maximum employment) - important constraint due to production capacity of contractor.
- System of contractual penalties related to delays of works (constraint takes under consideration requirement of schedule continuum –SC, and penalties related to due-to-time overrun of the investment – TO) [1]

Calculations were performed using Microsoft Excel software (as it is a common tool used in construction companies). Two algorithms were compared: genetic algorithm (GA) – calculated by Pikaia.f (ver. 1.2) [3] (open source version) and tabu search algorithm (TS) – calculated by Crystal Ball OptQuest software, commercial programme [4]. A stochastic attempt is also presented as a third result group, in order to compare results of deterministic methods with Monte Carlo simulation. Third algorithm was based on tabu search case but took under consideration assumption that costs of summary tasks (work packages) can be described as probability distribution. For the purpose of this example, triangular distributions were selected for every work package cost, with mean value equal to base values from GA and TS calculations, and minimum and maximum values defined as minus and plus 10% of mean value. Triangular distribution is an approximation of real time probability of events, but its advantage is that it is very easy to define using experience from previously finished projects and data acquired from experts.

3.2. Example

In the presented example, contractor builds a sport facility, consisting of three varying buildings of similar technology. Each building has a defined list of summary tasks (work packages) such as preparation works, ground works, foundation works, concrete works, technological breaks, finishing works etc. Financing assumption: invoices are issued every month, discount rate is 10%, indirect costs 75 000 EUR/day; penalty of each day of overrun 2 500 EUR. Due-to-time – 7 months = 147 workdays.

Initial version of the schedule predicted simultaneous realization of all three buildings. Tasks were arranged by introducing delays (which gave approx. $8x10^{22}$ possible results). All six possibilities of prioritizing building realization were checked. Results are shown in a following tables. Symbol "+" means that a constraint is fulfilled and symbol "-" that it is not. Apart from mentioned above parameters, additional parameters were presented (table 2): Net Present Value (NPV) and duration (t).

Table 1. Results comparison – objective function parameters

Parameters	Parallel execution of works	Object by object (6 variants)		GA (20 runs)		TS - deterministic (20 runs)		TS - stochastic (20 runs)	
CFmax [EUR]	639 998	Max:	198 526	Max:	317 317	Max:	275 843	Max:	287 796
		Mean:	194 350	Mean:	293 589	Mean:	260 467	Mean:	275 833
		Min:	192 086	Min:	277 028	Min:	229 716	Min:	263 377
WB	-	+		+		+		+	
ME	+	+		+		+		+	
SC	+	+		+		+		+	
TO	+	-		+		+		+	

Table 2. Results comparison – other parameters

Parameters	Parallel execution of works	Object by object (6 variants)		GA (20 runs)		TS - deterministic (20 runs)		TS - stochastic (20 runs)	
NPV [EUR]	346 968	Max:	339 998	Max:	401 192	Max:	386 027	Max:	389 110
		Mean:	339 807	Mean:	390 932	Mean:	384 258	Mean:	388 095
		Min:	339 612	Min:	373 514	Min:	383 373	Min:	379 444
t [days]	98	Max:	216	Max:	140	Max:	129	Max:	132
		Mean:	216	Mean:	132	Mean:	128	Mean:	129
		Min:	216	Min:	119	Min:	127	Min:	123

4. Conclusions

In the described example, the lowest CFmax was obtained (while satisfying the constraints) with the use of OptQuest application (TS – deterministic). The results calculated by this software were also characterized by greater consistency (smaller difference between the maximum and minimum value of CFmax). Tabu search algorithm – stochastic variant, in this example gives very similar key results to tabu search – deterministic variant. As expected, difference can be identified mainly in wider range of results and higher value of standard deviation of probability distributions. Running a tabu search algorithm with Monte Carlo simulation is a time-consuming method, since a single simulation pass includes several hundred or thousands additional simulations of defined assumptions. Based on presented example authors draw a conclusion, that stochastic TS algorithm would give slightly better results that TS deterministic (and a lot better results than GA), but time needed to complete such simulation properly will increase exponentially with complexity of project's assumptions and therefore can be difficult to use by a contractor. If however, contractor can afford such prolonged period of calculations, results should satisfy its needs.

In the future, the authors intends to compare other metaheuristic algorithms (i.e. ACO, SA) and other versions of algorithms already compared. It is also planned to compare the time of obtaining acceptable solutions by different software.

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