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Automatic time-cost trade-off for construction projects using evolutionary algorithm integrated into a scheduling software program developed with .NET framework

Phân tích cân bằng chi phí tiến độ của dự án sử dụng thuật toán tiến hóa tích hợp trong chương trình CPM Scheduling phát triển trên nền tảng .NET

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Abstract

In the field of construction management, the goal of time-cost tradeoff analysis is to find an optimal schedule featuring the smallest total cost; meanwhile, the requirement of the project schedule must be satisfied. In this research, a novel method for construction project time-cost tradeoff analysis is proposed. This article aims at developing an open tool for performing CPM based project scheduling visualization and time-cost tradeoff analysis. The success-history based parameter adaptation for Differential Evolution with linear population size reduction, denoted as LSHADE, is used for automatic time-cost tradeoff optimization. The new tool has been developed with .NET framework 4.6.2. Experimental result with a demonstrative project confirms that the newly developed software program can be a useful tool to assist project managers.

Keywords: Project Schedule Management; Critical Path Method; Time-Cost Tradeoff Analysis, Differential Evolution, .NET Framework.

Tóm tắt

Trong lĩnh vực quản lý xây dựng, phân tích cân bằng chi phí-tiến độ có mục tiêu tìm ra tiến độ tối ưu cho dự án sao cho có tổng chi phí nhỏ nhất, đồng thời thỏa mãn yêu cầu về tiến độ. Mục tiêu là rút ngắn thời gian dự án trong khi giảm thiểu chi phí trực tiếp và gián tiếp. Trong nghiên cứu này, một phương pháp mới được đề xuất cho việc phân tích cân bằng chi phí-tiến độ. Thuật toán tiến hóa vi phân tự thích nghi, ký hiệu là LSHADE, được sử dụng để tự động hóa quá trình phân tích cân bằng chi phí-tiến độ. Công cụ mới được phát triển trên nền tảng .NET 4.6.2. Kết quả thử nghiệm với một dự án chỉ ra rằng chương trình phần mềm được đề xuất có thể là một công cụ hữu ích để hỗ trợ các nhà quản lý dự án.

Từ khóa: Quản lý tiến độ dự án; phương pháp đường Găng; phân tích cân bằng chi phí - tiến độ, thuật toán tiến hóa, nền tảng .NET.

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1. Introduction

A construction project typically consists of a set of activities with their technical/managerial constraints. The nature of the construction industry, which is characterized by constant changes in the environment, pressures to maintain schedules/costs with increasingly complex construction techniques, makes project management a very challenging task [1-3]. Because of the complexity of construction projects, cost and schedule overruns are widely observed [2, 4, 5].

In addition, project owners as well as construction contractors often have a great motivation to reduce the project time. It is because besides direct costs, a project consumes a considerable amount of indirect costs, consisting of the cost of facilities, equipment, and machinery, interest on investment, utilities, labor, and the loss of skills/labor of the employed project [6]. Contractors may suffer from severe financial penalty for not completing a project on time. Moreover, project owners often want to complete the project as soon as possible to put their facilities into operation.

In practice, to reduce the project schedule, managers accelerate some of the activities at an additional cost, i.e., by allocating more or better resources. In addition, shortened project duration can lead to lower indirect costs. The task of finding an optimal project schedule with a minimum sum of direct and indirect costs is often known as the time-cost tradeoff. Since a project may have a large number of activities with sophisticated relationships among them, there is a practical need of project managers to perform the time-cost tradeoff automatically and to visualize the project duration quickly.

In recent years, the applications of evolutionary algorithms for project schedule optimization have increasingly gained more attentions of the research community [2, 7-11]. Evolutionary algorithms have been successfully used to optimize project schedule with respect to time-cost tradeoff [12-14]. Nevertheless, open tools for automatic time-cost tradeoff analysis are rarely found. Such tools can be very helpful for practical uses. Thus, this study develops a software program for CPM based project time cost tradeoff analysis as well as quick visualization of project schedule. The success-history based parameter adaptation for Differential Evolution with linear population size reduction (LSHADE) metaheuristic [15, 16] is employed in this study. The newly developed program has been developed in .NET framework 4.6.2 and tested with a demonstrative project.

2. Problem formulation

The project time cost tradeoff analysis can be defined as minimizing a project's total cost while meeting a specified project deadline. Hence, the objective function is a sum of the direct and indirect costs. The project direct cost can be computed by summing all activities' direct costs. The project indirect cost is often assumed to be dependent of the project schedule. The decision variables are activities' durations. The parameters of the problem at hand are the activities' relationships (e.g. finish-start), the time-cost relationships, and the pre-specified project duration [6, 17].

The problem of interest can be mathematically formulated as follows:

$$\text{Minimize } \sum_{\forall i} c_i + IDC \quad (1)$$

where $\sum_{\forall i} c_i$ is the sum of the activity direct cost, IDC = indirect cost.

Subject to

$$ES_i + t_i - ES_j \leq 0, \ \forall j \in A_i \quad (2)$$

$$D = \max_{\forall i}\{ES_i + t_i\} \leq D_o \quad (3)$$

$$ES_i,\ t_i \geq 0,\ \forall_i \tag{4}$$

$$c_i = f(t_i),\ \forall i \tag{5}$$

Eq. (2) means the precedence constraints between activity *i* and all the activities in its successor set A_i; t_i denotes the duration for activity *i*; ES_i is the early start time for activity *i*. Eq. (3) computes the total project duration, which must be smaller than the project deadline D_o. Eq. (4) means that all the early start times and activity durations are non-negative. Eq. (5) means that the cost of an activity (c_i) is a function of its duration (t_i).

The indirect cost (*IDC*) can be obtained as follows:

$$IDC = U_{IDC} \times D \tag{6}$$

where U_{IDC} denotes the amount of daily indirect cost.

3. The Evolutionary Algorithm of LSHADE

The LSHADE, put forward by [15, 16], is a powerful evolutionary algorithm for solving complex optimization problems. This advanced algorithm is developed based on the standard Differential Evolution [18]. The LSHADE inherits the DE's novel crossover-mutation operator using a linear combination of three different individuals and one subject-to-replacement parent (or target vector) [2, 6, 19].

Tanabe and Fukunaga [15] enhanced the standard DE algorithm with several improvements:

(i) The mutation scale factor (*F*) and the crossover probability (*CR*) are fine-tuned during the optimization process instead of being fixed values.

(ii) A mutation strategy called DE/current-to-pbest/1 is used to better explore the search space [16]:

$$v_{i,g+1} = x_{i,g} + F_i(x_{r1,g} - x_{r2,g}) + F_i(x_{pbest,g} - x_{i,g}) \tag{7}$$

where $v_{i,g+1}$ denotes a trial vector; $x_{i,g}$ is a target vector; $x_{r1,g}$, $x_{r2,g}$ represent two randomly selected members; $x_{pbest,g}$ denotes the current best solution.

(iii) A population size shrinking strategy is used to enhance convergence rate and to reduce computational expense.

The crossover operation aims at combining the information of the newly created candidate and its parent and can be expressed as follows [20]:

$$u_{j,i,g+1} = \begin{cases} v_{j,i,g+1},\ if\ \ rand_j \leq Cr\ or\ \ j = rnb(i) \\ x_{j,i,g},\ if\ \ rand_j > Cr\ and\ \ j \neq rnb(i) \end{cases} \tag{8}$$

(iv) The L-SHADE employs two archives of MF and MCR which are vectors of a fixed length *H* to update the *CR* and *F* values adaptively during the evolutionary process [21].

4. Software program application

The user needs to provide the project information containing the project name, activity names, activity durations, and activity predecessors. The project schedule is then computed automatically using the CPM method. After the CPM based schedule is computed, the LSHADE is used to perform the resource leveling process; this metaheuristic method attempts to shift noncritical activities within their float values to seek for an optimal project schedule. The demonstrative project contains 14 activities. The project information is provided in **Table 1**. The project schedule calculation based on the CPM method is shown in **Fig. 1** with the project duration of 28 days and the maximum worker demand of 30 for both early and late start schedules. The resource leveling outcome is illustrated in **Fig. 2** with the maximum worker demand being reduced to 25. The project duration remains to be 28 days.

The graphical user interface of the software program is illustrated in **Fig. 1**. The input information includes the project name, activity names, activity durations, and activity predecessors (refer to **Table 1**). The time-cost tradeoff analysis module requires information regarding the normal cost/duration, the crashed cost/duration, and the relaxed cost/duration of all activities (refer to **Table 2**). Based on these pieces of information, the computer program automatically performs analysis of time-cost trade-off and delivers the optimized project schedule.

An exemplary project described in **Table 1** and **Table 2** is used to test the program performance. The exemplary project consists of 14 activities. The maximum project duration is set to be 30 days; the direct cost is $200/day. The LSHADE based time-cost trade-off result is reported in **Fig. 2** with the total project cost = $19100, the total direct cost = $14300, the total indirect cost = $4800, and the project duration = 24 days. It can be seen that the program can deliver the project schedule which is smaller than the pre-specified project duration of 30 days.

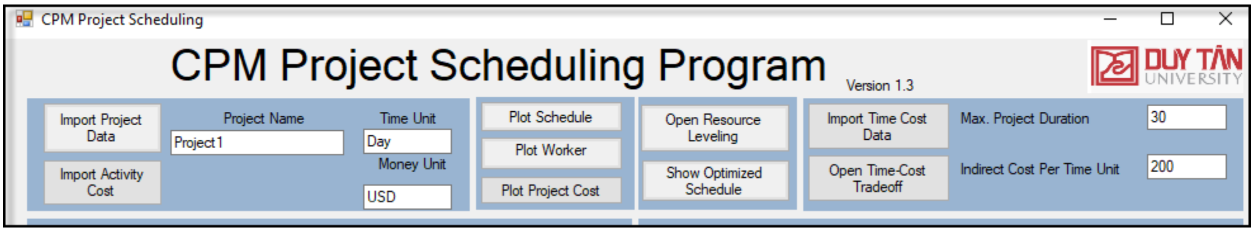

Fig. 1 The CPM scheduling program

Table 1 Information of the experimental project

Activity	Activity Name	Predecessors		
1	Site Preparation	0	0	0
2	Fence Construction	1	0	0
3	Site Electrical System	1	0	0
4	Site Water System	1	0	0
5	Temporary House	2	3	4
6	Site Excavation	5	0	0
7	Soil Improvement	6	0	0
8	Scaffolding Setup	6	7	0
9	Foundation Formwork	6	7	0
10	Foundation Rebar	6	7	0
11	Foundation Concrete	8	9	10
12	Concrete Curing	11	0	0
13	Formwork Removal	12	0	0
14	Finishing Tasks	12	13	0

Table 2 Time cost information

Activity	Crashed Duration	Normal Duration	Relaxed Duration	Crashed Cost	Normal Cost	Relaxed Cost
1	1	2	3	100	80	70
2	1	2	5	1200	600	300
3	1	6	5	1000	800	600
4	1	4	3	800	600	400
5	1	3	5	600	400	200
6	1	3	5	2100	1700	1300
7	1	5	8	4100	3700	3300
8	1	1	8	1100	1000	900
9	1	3	6	2100	1700	1300
10	1	2	4	3100	2700	2300
11	1	2	4	500	300	200
12	1	2	4	1100	700	400
13	1	2	4	600	400	300
14	1	2	5	500	300	200

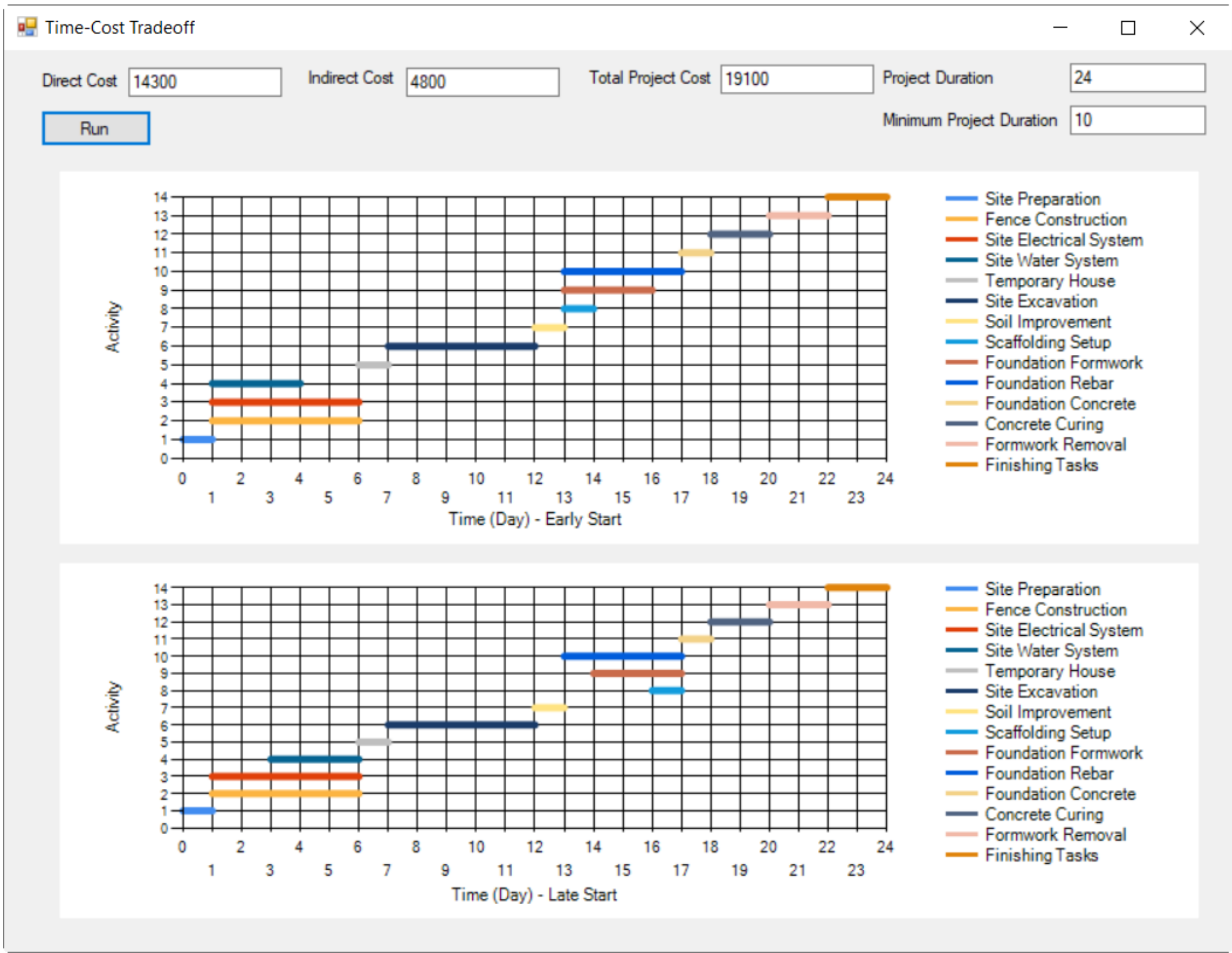

Fig. 2 Time-cost trade-off analysis result

5. Conclusion

This study develops a software program, denoted as CPM project scheduling, for performing the project time-cost trade-off automatically. The LSHADE evolutionary algorithm is used to to optimize the project schedule. The resulting schedule (both early and late starts) can be conveniently visualized using the charts created by the program. The program is tested with an exemplary project consisting of 14 activities. Experimental outcome demonstrates that the newly developed tool is promising tool to assist project managers in developing cost-effective project schedules.

Supplementary material

The software program can be downloaded at: http://github.com/NhatDucHoang/CPM ProjectSchedulingV1.3.

References

[1] M.-Y. Cheng, D.-H. Tran, and N.-D. Hoang, "Fuzzy clustering chaotic-based differential evolution for resource leveling in construction projects," *Journal of Civil Engineering and Management*, vol. 23, pp. 113-124, 2017/01/02 2017.

[2] N.-D. Hoang, Q.-L. Nguyen, and Q.-N. Pham, "Optimizing Construction Project Labor Utilization Using Differential Evolution: A Comparative Study of Mutation Strategies," *Advances in Civil Engineering*, vol. 2015, p. 8, 2015.

[3] D. W. Halpin and B. A. Senior, *Construction Management*: Wiley, 4 edition, 2010.

[4] N. Al-Hazim, Z. A. Salem, and H. Ahmad, "Delay and Cost Overrun in Infrastructure Projects in Jordan," *Procedia Engineering*, vol. 182, pp. 18-24, 2017/01/01/ 2017.

[5] M. Cavalieri, R. Cristaudo, and C. Guccio, "On the magnitude of cost overruns throughout the project life-cycle: An assessment for the Italian transport infrastructure projects," *Transport Policy*, vol. 79, pp. 21-36, 2019/07/01/ 2019.

[6] N.-D. Hoang, "NIDE: A Novel Improved Differential Evolution for Construction Project Crashing Optimization," *Journal of Construction Engineering*, vol. 2014, p. 7, 2014.

[7] H. Alsayegh and M. Hariga, "Hybrid meta-heuristic methods for the multi-resource leveling problem with activity splitting," *Automation in Construction*, vol. 27, pp. 89-98, 2012/11/01/ 2012.

[8] M.-Y. Cheng, K.-Y. Huang, and M. Hutomo, "Multiobjective Dynamic-Guiding PSO for Optimizing Work Shift Schedules," *Journal of Construction Engineering and Management*, vol. 144, p. 04018089, 2018.

[9] L. Zhu, J. Lin, and Z.-J. Wang, "A discrete oppositional multi-verse optimization algorithm for multi-skill resource constrained project scheduling problem," *Applied Soft Computing*, vol. 85, p. 105805, 2019/12/01/ 2019.

[10] N. Balouka and I. Cohen, "A robust optimization approach for the multi-mode resource-constrained project scheduling problem," *European Journal of Operational Research*, 2019/09/28/ 2019.

[11] H.-H. Tran and N.-D. Hoang, "A Novel Resource-Leveling Approach for Construction Project Based on Differential Evolution," *Journal of Construction Engineering*, vol. 2014, p. 7, 2014.

[12] P. Wuliang and W. Chengen, "A multi-mode resource-constrained discrete time–cost tradeoff problem and its genetic algorithm based solution," *International Journal of Project Management*, vol. 27, pp. 600-609, 2009/08/01/ 2009.

[13] D.-H. Tran, L. Luong-Duc, M.-T. Duong, T.-N. Le, and A.-D. Pham, "Opposition multiple objective symbiotic organisms search (OMOSOS) for time, cost, quality and work continuity tradeoff in repetitive projects," *Journal of Computational Design and Engineering*, vol. 5, pp. 160-172, 2018/04/01/ 2018.

[14] H. Zhang and F. Xing, "Fuzzy-multi-objective particle swarm optimization for time–cost–quality tradeoff in construction," *Automation in Construction*, vol. 19, pp. 1067-1075, 2010/12/01/ 2010.

[15] R. Tanabe and A. S. Fukunaga, "Improving the search performance of SHADE using linear population size reduction," in *2014 IEEE Congress on Evolutionary Computation (CEC)*, 2014, pp. 1658-1665.

[16] R. Tanabe and A. Fukunaga, "Success-history based parameter adaptation for Differential Evolution," in *2013 IEEE Congress on Evolutionary Computation*, 2013, pp. 71-78.

[17] I.-T. Yang, "Using Elitist Particle Swarm Optimization to Facilitate Bicriterion Time-Cost Trade-Off Analysis," *Journal of Construction Engineering and Management*, vol. 133, pp. 498-505, 2007.

[18] R. Storn and K. Price, "Differential Evolution – A Simple and Efficient Heuristic for global Optimization over Continuous Spaces," *Journal of Global Optimization*, vol. 11, pp. 341-359, December 01 1997.

[19] E. Mezura-Montes, M. E. Miranda-Varela, and R. del Carmen Gómez-Ramón, "Differential evolution in constrained numerical optimization: An empirical study," *Information Sciences*, vol. 180, pp. 4223-4262, 2010/11/15/ 2010.

[20] K. Price, R. M. Storn, and J. A. Lampinen, *Differential Evolution - A Practical Approach to Global Optimization*: Springer-Verlag Berlin Heidelberg, 2005.

[21] T.-D. Nguyen, T.-H. Tran, H. Nguyen, and H. Nhat-Duc, "A success history-based adaptive differential evolution optimized support vector regression for estimating plastic viscosity of fresh concrete," *Engineering with Computers*, December 18 2019.