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Time-Cost Trade-Off problem in project management: A proposed constructive algorithm

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Abstract
Time and cost are two remarkable elements prescriptive of success in project management. The anticipated project length may go over the desired period in many projects. Therefore, it becomes vital to shorten the critical path in order to finish the project by the goal date. Time-cost trade-off (TCT) in project network, the reduction in time with a minimum cost of project activities, has increased efficiency of the project. To shorten a project duration activity crashing, which includes allocating additional resources to an activity with the objective of diminishing its duration, is the most commonly employed compression technique. The objective of an optimum solution of time-cost trade-off is to provide maximum profit opportunity with a minimum time. There are many algorithms (heuristic, meta-heuristic and exact) established in this regard. In this paper a constructive algorithm is proposed and implemented with a fairy application example to acquire optimum solution or close-optimum solution of TCT problems.

Keywords Critical path, Time-Cost Trade-off, Crash, Proposed constructive algorithm, Cost-slope.

Paper type Research paper

1. Introduction

In the construction sector, construction management is a relatively new field. Its impact, on the other hand, has been enormous. It is now a widely used strategy for improving the efficiency of building projects in everywhere. In the construction sector, construction management is a relatively new field. Its impact, on the other hand, has been enormous. Due to the entry of new enterprises into the market, competition in the construction industry has been increasing. As a result, project management struggles to identify the most effective schedule based on a variety of factors such as time, money, and other operational resources. The ability to complete a project in minimum time and at a lower cost is an important factor to consider while designing a structure. Accelerating the project

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timetable, on the other hand, costs more because the activity length is reduced, necessitating the use of extra resources. Decision makers can perform a TCT problem if a project is running behind schedule. TCTP assists in familiarizing oneself with the collection of time–cost options that will ensure the best timetable under certain conditions.

2. Existing methods of Time-Cost Trade-off

The time of a project can be shortened by spending more money to expedite important processes. The expense of a critical activity raises when the activity is crashed, shortening the project's duration. The indirect cost is reduced when the project time is reduced, Optimum project budget in Time-Cost Trade-off situations is sought (Hegazy, 1999a)

The significance of the TCT matter was identified nearly alongside with the outline of project investigation methods (Kelley Jr. & Walker, 1959; Kelley Jr, 1961; Fulkerson, 1961). Some heuristic methods have been created with the goal of finding the best answer to TCT problems. The heuristic algorithm developed by Siemens (1971) was the first significant attempt to address the TCT problem, and further (Goyal, 1975; Siemens, & Gooding, 1975) enhanced this algorithm. Heuristic methods for TCT with linear cost curves were further developed by Barber and Boardman (1988), Chiu and Chiu (2005). The above-mentioned methods afford the best result for continuously crashing jobs, but they cannot assurance convergence to the worldwide best for discrete or non-linear crashes. Berman (1964) devised a method for optimizing networks with continuous cost functions that are concave. Falk and Horowitz (1972) used the branch-and-bound algorithm to investigate concave continuous cost functions. Vanhoucke (2005) also suggested the BaB method for the TCT problem. TCT was also solved using network decomposition methods (Vanhoucke & Debels, 2007; Schwarze, 1980; Demeulemeester, Herroelen, & Elmaghraby, 1996; Demeulemeester, De Reyck, Foubert, Herroelen, & Vanhoucke, 1998; Haz r, Haouari, & Erel, 2010).

Srivastava and Pathak (2014) used a neural network to solve the TCT problem. Lower boundaries for time-cost relationships are provided by integer programming, mixed integer programming and linear programming. IP, LP and mixed-integer are established (Sakellaropoulos & Chassiakos, 2004; Moussourakis & Haksever, 2004; Bidhandi, 2006; Hazr, Haouari, & Erel, 2010; Liberatore & Pollack-Johnson, 2006; Liu, Burns, & Feng, 1995; Al Haj & El-Sayegh, 2015; Moussourakis & Haksever, 2007).

TCT (De, Dunne, Ghosh, & Wells, 1997) is the search domain which grows much quicker than the project size, known as NP-Hard. As a result, the memory requirements and computational demands of accurate algorithms skyrocket. For the solution of TCT, GA is by far the most popular meta-heuristic algorithm (Lee, Roh, Park, & Ryu, 2010; Zhang & Xing, 2010; Li, Cao, & Love, 1999; Bettemir, 2009; Feng, Liu, & Burns, 1997; Hegazy, 1999a). Shuffled Frog Leaping and the Hybrid Genetic Algorithm successfully determine small projects in a sensible amount of time (Sonmez & Bettemir, 2012; Elbeltagi, Hegazy, & Grierson, 2005). For large projects, however, an optimal or near-optimal solution necessitates nearly 1.5 million schedule evaluations (Bettemir, 2009). Furthermore, for the TCT problem, (Anagnostopoulos & Kotsikas, 2010) Simulated Annealing is (Anagnostopoulos & Kotsikas, 2010; Yang, 2007) implemented Particle Swarm Optimization, and (Zhang & Thomas, 2012; Zhang & Xing, 2010) employed Ant Colony Optimization, hybrid evolutionary algorithm (Rogalska, Bo ejko, & Hejducki, 2008; Geem, 2010) used Harmony Search. Using Building Information System software TCT was studied by Cha and Lee (2015).

Time and money aren't the only factors to consider while designing a project. As a result, different variations of the time-cost trade-off dilemma are investigated. Time-cost-quality trade-off is improved by adding quality to the TCT problem (Babu & Suresh, 1996; Monghasemi, Nikoo, Fasaee, & Adamowski, 2015; Khang & Myint, 1999; Kim, Kang, & Hwang, 2012; Tareghian & Taheri, 2006; Tavana, Abtahi, & Khalili-Damghani, 2014; Zhang & Xing, 2010; Mungle, Benyoucef, Son, & Tiwari, 2013).

In TCT, time and cost required options are considered to be predictable. Both activity costs and durations, on the other hand, are unpredictable, (Yang, 2005; Kalhor, Khanzadi, Eshtehardian, & Afshar, 2011; Azaron, Perkgoz, & Sakawa, 2005; Zheng, Ng, & Kumaraswamy, 2005; Leu, Chen, & Yang, 2001; Ke, Ma, & Ni, 2009; Li & Wang, 2009; Yang, 2011; Xu, Zheng, Zeng, Wu, & Shen, 2012; Eshtehardian, Afshar, & Abbasnia, 2009; Said & Haouari, 2015; Chen & Tsai, 2011).

TCT matter is solved by presuming an endless supply of resources. When resources are limited in quantity, the problem is referred to as multi-mode resource restricted project scheduling. TCT with restricted resources to account for resource availability is solved (Liu & Wang, 2008; Hegazy, 1999b; Ghoddousi, Eshtehardian, Jooybanpour, & Javanmardi, 2013; Cheng & Tran, 2016; Rostami, Moradinezhad, & Soufipour, 2014; Afruzi, Najafi, Roghanian, & Mazinani, 2014).

TCT problem was solved by Metwally and Elazouni (2007) by reducing the negative cash flow, while (Ammar, 2011) was solved it by optimizing the principal. Furthermore, (Fathi & Afshar, 2010) used GA to optimize the

NPV of the profit, whereas Koo, Hong and Kim (2015) solved the Time-Cost situation trade-off by introducing ecological impact.

To summarize, meta-heuristic algorithms are computationally intensive, heuristic methods do not always show a proper solution, and proper techniques are difficult for building organizers to perform. Thus, a reliable constructive algorithm for the distinct Time-Cost Trading issue is till now missing. The best solution for the united TCT problem is found using the minimum cost slope approach. However, because discrete crashing choices limit the creation of linear cost functions, the approach is not appropriate for the distinct TCT problem. To solve the distinct TCT problem, a simple, maximum converging, and fast network analysis technique stimulated by the lowest cost-slope procedure is suggested in this study.

3. Proposed model structure

PCA (Proposed Constructive Algorithm) finds the best schedule by crashing activities one by one. The crashing possibilities are not chosen grounded on the greatest advantage, because the greatest advantage might not have been the greatest option if the staff conditions are removed. When a project is completed forward of schedule, however, the prize becomes a permanent payment. The crashing cost is contrasted to the entire of the incentive and the indirect cost in this situation.

The technique for reducing the project duration with minimum cost can be abridged in the following phases:

Step-01: Enumerate the cost slope of each activity.
Step-02: Determine all possible paths of the network.
Step-03: Determine the critical path(s).
Step-04: If there be a single critical path, find the activity with the minimum crashing slope in the critical path.
Step-05: Estimate the reducing(saving) time.
Step-06: If there are multi critical paths, determine the crashing combinations.
Step-07: Find the lowest combination crashing curve.
Step-08: Go to step-06.
Step-09: If the crashing is feasible, then crash the activity (or combination of activities).
Step-10: Is the path(s) should be rescheduled?
Step-11: If yes, evaluate schedule and then go to step-04.
Step-12: If no, then go to step-04.
Step-13: If the crashing is not feasible, then select the untried crashing choice

with the minimum crashing cost and then go to step-06.

Step-14: If the crashing is fuzzy, then evaluate schedule.

Step-15: Test the feasibility of crashing.

Step-16: If yes, then go to the step-10.

Step-17: If no, determine any other crashing opportunity.

Step-18: If there is a crashing opportunity, then go to the step-14.

Step-19: If there is no other crashing opportunity, search through the activities with float to find feasible combination.

Step-20: If there be new combination found, then go to the step-10.

Step-21: If there be no new combination found, then Time-Cost Trading-off is finished.

The search method identifies a large number of crashing alternatives, which necessitates a large amount of processing. The proposed strategy, on the other hand, is designed to be fast convergent. As a result, the crashing possibilities must be evaluated without regard to the timeline. If a path which is not critical with insufficient total float becomes critical, crashing does not result in the predicted reduction in project length. On either hand, the accelerated activity may shorten non-critical pathways, resulting in the anticipated project duration reduction.

4. Numerical example with calculation

This algorithm examined on a project of 18-activity which was propagated by Burns, Liu and Feng (1996) and reformed by Hegazy (1999a). There are 2 to 5 different duration and cost choices for each activity.

The number of possible different alternatives of cost-duration here is:

$$55 * 42 * 310 * 21 = 5904900000$$

Even on a high-speed computer, a complete examination of this maximum value takes a significant amount of time. As a result, carrying out a thorough enumeration is nearly difficult. The analysis of the project is applicable for the following 2 cases:

i. Minimum overall project cost based on an overhead cost of constant $210/day and a $1000/day incentive for earlier completions starting at 110 days and liquidated damages of $20000/day for after completions starting at 110 days.

ii. Minimum overall project cost based on an overhead cost of constant $210/day.

Activity	Predecessor	Normal		Crash-01		Crash-02		Crash-03		Crash-04	
		Dur (Day)	Cost ($)	Dur (Day)	Cost ($)	Dur (Day)	Cost ($)	Dur (Day)	Cost ($)	Dur (Day)	Cost ($)
1	-	24	1200	19	2100	21	3200	23	1450	23	1450
2	-	25	1000	22	2000	23	1900	22	2800	23	2200
3	-	33	3200	26	12000	22	4400	-	-	-	-
4	-	20	300000	16	50000	16	70000	-	-	-	-
5	1	30	10000	26	20000	28	20000	-	-	-	-
6	1	24	18000	20	102000	18	34000	-	-	-	-
7	5	18	22000	12	28000	15	58000	-	-	-	-
8	6	24	120	19	424	21	160	23	125	23	135
9	6	25	100	22	220	23	160	22	280	23	220
10	2, 6	33	320	26	1200	22	720	-	-	-	-
11	7, 8	20	300	16	500	16	400	-	-	-	-
12	5, 9, 10	30	1000	26	1000	28	1400	-		28	-
13	3	24	1800	20	10200	18	2800	-	-	-	-
14	4,10	18	2200	12	2800	15	5400	-	-	-	-
15	12	16	3500	-	7500	12	-	-	-	-	-
16	13, 14	30	1000	26	2000	28	2000	28	3000	28	1500
17	11, 14, 15	24	1800	20	10200	18	5000	-	-	-	-
18	16, 17	18	2200	12	2800	15	5800	-	-	-	-

Table 1
Cost Slope Procedure of Each Activity

Activity	Predecessor	Normal		Crash-01		Crash-02		Crash-03		Crash-04	
		Dur. (Day)	Cost ($)	Exp-ected	Avg Cost	Exp-ected	Avg Cost	Exp-ected	Avg Cost	Exp-ected	Avg Cost
1	-	24	1200	5	300	3	400	1	250	1	250
2	-	25	1000	3	500	2	300	2	600	3	600
3	-	33	3200	7	800	11	500	-	-	-	-
4	-	20	300000	4	5000	4	10000	-	-	-	-
5	1	30	10000	4	5000	2	2500	-	-	-	-
6	1	24	18000	4	14000	6	8000	-	-	-	-
7	5	18	22000	6	2000	3	6000	-	-	-	-
8	6	24	120	5	88	3	8	1	5	1	15
9	6	25	100	3	50	2	30	2	60	3	60
10	2, 6	33	320	7	80	11	50	-	-	-	-
11	7, 8	20	300	4	50	4	100	-	-	-	-
12	5, 9, 10	30	1000	4	500	2	250	2	-	-	250

Activity	Predecessor	Normal Dur. (Day)	Normal Cost ($)	Crash-01 Expected	Crash-01 Avg Cost	Crash-02 Expected	Crash-02 Avg Cost	Crash-03 Expected	Crash-03 Avg Cost	Crash-04 Expected	Crash-04 Avg Cost
13	3	24	1800	4	1400	6	800	-	-	-	-
14	4,10	18	2200	6	200	3	600	-	-	-	-
15	12	16	3500	-	1000	4	-	-	-	-	-
16	13, 14	30	1000	4	500	2	250	2	1000	2	250
17	11, 14, 15	24	1800	4	1400	6	800	-	-	-	-
18	16, 17	18	2200	6	200	3	600	-	-	-	-

Table 2

Crashing Procedure of the 1st Case Problem

Crashing Activity	Crash Cost	Acquired Benefit	Direct Cost	Project Duration	Indirect Cost	Total Cost
-	-	-	99740	169	35490	135230
10	80	1600	99820	161	33810	133630
9	50	400	99870	159	33390	133260
9	30	200	99900	158	33180	133080
10	50	400	99950	156	32760	132710
9	60	400	100010	154	32340	132350
9	60	600	100070	151	31710	131780
18	200	600	100270	148	31080	131350
1	300	600	100570	145	30450	131020
1	400	1000	100970	140	29400	130370
18	600	1200	101570	134	28140	129710
12*	750	1200	102320	128	26880	129200
12	250	400	102570	126	26460	129030

Table 3

Crashing Procedure of the 2nd Case Problem

Crashing Activity	Crash Cost	Acquired Benefit	Direct Cost	Project Duration	Indirect Cost	Total Cost
-	-	-	99740	169	1214590	1314330
10	80	161600	99820	161	1053810	1153630
9	50	40400	99870	159	1027700	1113260
9	30	20200	99900	158	993180	1093080
10	50	40400	99950	156	952760	1052710
9	60	40400	100010	154	912340	1012350
9	60	60600	100070	151	851710	952780
18	200	60600	100270	148	791080	891350
1	300	60600	100570	145	730450	831020
1	400	101000	100970	140	629400	730370

Crashing Activity	Crash Cost	Acquired Benefit	Direct Cost	Project Duration	Indirect Cost	Total Cost
18	600	121200	101570	134	508140	609710
17	1400	121200	102970	128	386880	489850
17	800	80800	103770	124	306040	409810
1	250	20200	104020	123	285830	389850
1	250	20200	104270	122	265620	369890
12	500	40400	104770	120	225200	329970
12	250	80800	105020	116	144360	249380
12	250	105270	40400	114	103940	209210
15	1000	106270	80800	110	23100	129370

Tables 01 through 03 show the crash sequences provided by PCA. The crashing number column displays the succession of crashes; the ID column displays the ID; the third column displays the project duration determined using the present development manners of the choices; The cost of the enabled crashing choice is displayed in the crashing cost column. The sum of the money saved by avoiding penalties, reducing indirect expenses, or earning awards is represented in the acquired benefit column. The minimum operation costs of the activity(s) as according existing structure techniques are represented in the 4th column. The sum of penalties and overhead costs is shown in the 6th column.; and total cost column signifies the sum of indirect and direct costs.

In Table-02, the activity is depicted as 12* in the 11th crashing to illustrate dual crashing. In 12 crashing, PCA converges to a worldwide best for the 1st case problem of the above project.

Table-03 depicts the crashing process of the 18-Activity Project's second case problem. In 18 crashing tries, the global optimum is found. The 1st and 2nd crashing choices of the 12th activity are carried out independently in this example, despite the fact that the 1st option's crashing slope is $250 per day and the above-mentioned crashing choice is viable due to the $20,000 daily penalty.

For the two case situations, global optima may be found with relatively minimal computational effort. In both situations, no trial schedule evaluation is conducted, demonstrating that the heuristic method is substantially faster than the metaheuristic algorithms in terms of convergence.

5. Result and discussion

PCA is being evaluated on project networks with 18 activities. For small and medium-sized networks, the proposed algorithm achieves global optimum in all case issues. Compared to meta-heuristic techniques, PCA requires substantially less computational and memory resources. If an unlimited schedule evaluation is undertaken, however, meta-heuristic algorithms can yield better outcomes.

According to the two case issues of the 18-Activity project, PCA converged to a global optimum. When the algorithm's computing effort and memory requirement are considered, the obtained local optima in both circumstances are still sufficient. The deviation from the ideal solution is 0.046 percent. The simulated annealing meta-heuristic algorithms and the genetic algorithm, on the other hand, diverged 2.61 percent and 2.50 percent after 50,000 trials (Elbeltagi, Hegazy, & Grierson, 2005), respectively. To attain the same local minima, the Simulated Annealing and Genetic Algorithm require around 200,000 schedule evaluations. To attain the same local minima, the Genetic Algorithm and Simulated Annealing require around 200,000 schedule evaluations.

Local minima removal is crucial in addition to convergence. Meta-heuristic algorithms assign survival probabilities based on individual fitness. The acquired cost savings in the total project cost is a measure of suitability for TCT difficulties. When the crashing expenses are between $50,000 and $20,000, the chances of survival may not be distinguishable between those who are well-fit and those who are not. In this instance, an incorrectly chosen crashing option with a modest crashing cost may go undetected. PCA, on the other hand, clearly identifies the ultimate of crashing costs and can be used to eliminate local minimums.

To reduce the processing demand of metaheuristic algorithms, PCA can be used to exclude infeasible areas of the search region. From the case study, disclose NAA's computational requirement grows in a linear fashion. The heuristic algorithm's property makes it a good choice for the large-scale project optimization. The number of crucial routes increases as the crashing method progresses, like the number of crashing possibilities.

Because of the deletion and neglection of crashing combinations, convergence of the PCA into global minima is not assured. For large projects, if crashing choices were produced without reducing the search area, over billions of crashing alternatives would be formed. As a result, in terms of computing power and memory, this arrangement is unworkable. On either hand, PCA can be combined with a network deconstruction technique to find viable crashing possibilities while ignoring the possibility of failure. If this is accomplished, PCA will be capable to attain worldwide optimal for all schemes, regardless of size or difficulty.

6. Conclusion

The discrete TCT problem is handled in this study using a network analysis method based on the least cost-slope method. The suggested approach is designed for Activity-on-Node networks, which make it easier to define activity precedence connections. PCA uses a step-by-step crashing approach to find the global optimum. Crashing choices are found by searching through the search domain's viable portion. The presence of distinct crashing alternatives necessitates the inclusion of non-critical operations in the exploration domain. Despite the presence of a vast search area, PCA filters out infeasible choices and chooses the crashing choice with the lowermost cost-slope.

The proposed constructive algorithm is put to the test by its capacity to locate the global optimum and the speed with which it converges. This algorithm converges to near-optimum or optimum solutions substantially faster than expected, according to the results of the tests. PCA has a far lower computational load than meta-heuristic techniques. Furthermore, the method is simpler to construct than branch-and-bound algorithms or, integer-programming and it produces better results than heuristic algorithms. As a consequence of the investigation, the proposed constructive algorithm is an appropriate optimization strategy for the isolated Time-Cost Trading-off problem.

References

Afruzi, E. N., Najafi, A. A., Roghanian, E., & Mazinani, M. (2014). A multi-objective imperialist competitive algorithm for solving discrete time, cost and quality trade-off problems with mode-identity and resource-constrained situations. *Computers & Operations Research, 50,* 80-96.

Al Haj, R. A., & El-Sayegh, S. M. (2015). Time–cost optimization model considering float-consumption impact. *Journal of Construction Engineering and Management, 141*(5), 04015001.

Ammar, M. A. (2011). Optimization of project time-cost trade-off problem with discounted cash flows. *Journal of Construction Engineering and Management, 137*(1), 65-71.

Anagnostopoulos, K. P., & Kotsikas, L. (2010). Experimental evaluation of simulated annealing algorithms for the time–cost trade-off problem. *Applied Mathematics and Computation, 217*(1), 260-270.

Azaron, A., Perkgoz, C., & Sakawa, M. (2005). A genetic algorithm approach for the time-cost trade-off in PERT networks. *Applied Mathematics and Computation, 168*(2), 1317-1339.

Babu, A. J. G., & Suresh, N. (1996). Project management with time, cost, and quality considerations. *European Journal of Operational Research, 88*(2), 320-327.

Barber, T. J., & Boardman, J. T. (1988). Knowledge-based project control employing heuristic optimisation. *IEE Proceedings A (Physical Science, Measurement and Instrumentation, Management and Education, Reviews), 135*(8), 529-538.

Berman, E. B. (1964). Resource allocation in a PERT network under continuous activity time-cost functions. *Management Science, 10*(4), 734-745.

Bettemir, Ö. H. (2009). Optimization of time-cost-resource trade-off problems in project scheduling using meta-heuristic algorithms. Published PhD Dissertation: Middle East Technical University, Turkey.

Bidhandi, H. M. (2006). A new approach based on the surrogating method in the project time compression problems. *Annals of Operations Research, 143*(1), 237-250.

Burns, S. A., Liu, L., & Feng, C. W. (1996). The LP/IP hybrid method for construction time-cost trade-off analysis. *Construction Management & Economics, 14*(3), 265-276.

Cha, H. S., & Lee, D. G. (2015). A case study of time/cost analysis for aged-housing renovation using a pre-made BIM database structure. *KSCE Journal of Civil Engineering, 19*(4), 841-852.

Cheng, M. Y., & Tran, D. H. (2016). An efficient hybrid differential evolution based serial method for multimode resource-constrained project scheduling. *KSCE Journal of Civil Engineering, 20*(1), 90-100.

Chiu, Y. S. P., & Chiu, S. W. (2005). Incorporating expedited time and cost of the end product into the product structure diagram. *International Journal of Machine Tools and Manufacture, 45*(7-8), 987-991.

De, P., Dunne, E. J., Ghosh, J. B., & Wells, C. E. (1997). Complexity of the discrete time-cost tradeoff problem for project networks. *Operations Research, 45*(2), 302-306.

Demeulemeester, E., De Reyck, B., Foubert, B., Herroelen, W., & Vanhoucke, M. (1998). New computational results on the discrete time/cost trade-off problem in project networks. *Journal of the Operational Research Society, 49*(11), 1153-1163.

Elazouni, A. M., & Metwally, F. G. (2007). Expanding finance-based scheduling to devise overall-optimized project schedules. *Journal of Construction Engineering and Management, 133*(1), 86-90.

Elbeltagi, E., Hegazy, T., & Grierson, D. (2005). Comparison among five evolutionary-based optimization algorithms. *Advanced Engineering Informatics, 19*(1), 43-53.

Eshtehardian, E., Afshar, A., & Abbasnia, R. (2009). Fuzzy-based MOGA approach to stochastic time–cost trade-off problem. *Automation in Construction, 18*(5), 692-701.

Falk, J. E., & Horowitz, J. L. (1972). Critical path problems with concave cost-time curves. *Management Science, 19*(4-part-1), 446-455.

Falkerson, D. R. (1961). A network-flow computation for project cost curve. *Management Science, 7*(2), 167.

Feng, C. W., Liu, L., & Burns, S. A. (1997). Using genetic algorithms to solve construction time-cost trade-off problems. *Journal of Computing in Civil Engineering, 11*(3), 184-189.

Geem, Z. W. (2010). Multiobjective optimization of time-cost trade-off using harmony search. *Journal of Construction Engineering and Management, 136*(6), 711-716.

Ghoddousi, P., Eshtehardian, E., Jooybanpour, S., & Javanmardi, A. (2013). Multi-mode resource-constrained discrete time–cost-resource optimization in project scheduling using non-dominated sorting genetic algorithm. *Automation in Construction, 30,* 216-227.

Goyal, S. K. (1975). Note—A note on "a simple CPM time-cost trade off algorithm". *Management Science, 21*(6), 718-722.

Haz r, Ö., Haouari, M., & Erel, E. (2010). Discrete time/cost trade-off problem: A decomposition-based solution algorithm for the budget version. *Computers & Operations Research, 37*(4), 649-655.

Hegazy, T. (1999a). Optimization of construction time-cost trade-off analysis using genetic algorithms. *Canadian Journal of Civil Engineering, 26*(6), 685-697.

Hegazy, T. (1999b). Optimization of resource allocation and leveling using genetic algorithms. *Journal of Construction Engineering and Management, 125*(3), 167-175.

Kalhor, E., Khanzadi, M., Eshtehardian, E., & Afshar, A. (2011). Stochastic time–cost optimization using non-dominated archiving ant colony approach. *Automation in Construction, 20*(8), 1193-1203.

Ke, H., Ma, W., & Ni, Y. (2009). Optimization models and a GA-based algorithm for stochastic time-cost trade-off problem. *Applied Mathematics and Computation, 215*(1), 308-313.

Kelley Jr, J. E. (1961). Critical-path planning and scheduling: Mathematical basis. *Operations Research, 9*(3), 296-320.

Kelley Jr, J. E., & Walker, M. R. (1959, December 1-3). *Critical-path planning and scheduling.* Papers presented Eastern joint IRE-AIEE-ACM computer conference (pp. 160-173).

Khang, D. B., & Myint, Y. M. (1999). Time, cost and quality trade-off in project management: A case study. *International Journal of Project Management, 17*(4), 249-256.

Koo, C., Hong, T., & Kim, S. (2015). An integrated multi-objective optimization model for solving the construction time-cost trade-off problem. *Journal of Civil Engineering and Management, 21*(3), 323-333.

Lee, H. S., Roh, S., Park, M. S., & Ryu, H. G. (2010). Optimal option selection for finishing works of high-rise building. *KSCE Journal of Civil Engineering, 14*(5), 639-651.

Leu, S. S., Chen, A. T., & Yang, C. H. (2001). A GA-based fuzzy optimal model for construction time–cost trade-off. *International Journal of Project Management, 19*(1), 47-58.

Li, C., & Wang, K. (2009). The risk element transmission theory research of multi-objective risk-time-cost trade-off. *Computers & Mathematics with Applications, 57*(11-12), 1792-1799.

Li, H., Cao, J. N., & Love, P. E. D. (1999). Using machine learning and GA to solve time-cost trade-off problems. *Journal of Construction Engineering and Management, 125*(5), 347-353.

Liberatore, M. J., & Pollack-Johnson, B. (2006). Extending project time–cost analysis by removing precedence relationships and task streaming. *International Journal of Project Management, 24*(6), 529-535.

Liu, L., Burns, S. A., & Feng, C. W. (1995). Construction time-cost trade-off analysis using LP/IP hybrid method. *Journal of Construction Engineering and Management, 121*(4), 446-454.

Liu, S. S., & Wang, C. J. (2008). Resource-constrained construction project scheduling model for profit maximization considering cash flow. *Automation in Construction, 17*(8), 966-974.

Monghasemi, S., Nikoo, M. R., Fasaee, M. A. K., & Adamowski, J. (2015). A novel multi criteria decision making model for optimizing time–cost–quality trade-off problems in construction projects. *Expert Systems with Applications, 42*(6), 3089-3104.

Moussourakis, J., & Haksever, C. (2007). Models for accurate computation of earliest and latest start times and optimal compression in project networks. *Journal of Construction Engineering and Management, 133*(8), 600-608.

Mungle, S., Benyoucef, L., Son, Y. J., & Tiwari, M. K. (2013). A fuzzy clustering-based genetic algorithm approach for time–cost–quality trade-off problems: A case study of highway construction project. *Engineering Applications of Artificial Intelligence, 26*(8), 1953-1966.

Pathak, B. K., & Srivastava, S. (2014). Integrated ANN-HMH approach for nonlinear time-cost tradeoff problem. *International Journal of Computational Intelligence Systems, 7*(3), 456-471.

Rogalska, M., Bożejko, W., & Hejducki, Z. (2008). Time/cost optimization using hybrid evolutionary algorithm in construction project scheduling. *Automation in Construction, 18*(1), 24-31.

Rostami, M., Moradinezhad, D., & Soufipour, A. (2014). Improved and competitive algorithms for large scale multiple resource-constrained project-scheduling problems. *KSCE Journal of Civil Engineering, 18*(5), 1261-1269.

Said, S. S., & Haouari, M. (2015). A hybrid simulation-optimization approach for the robust Discrete Time/Cost Trade-off Problem. *Applied Mathematics and Computation, 259,* 628-636.

Sakellaropoulos, S., & Chassiakos, A. P. (2004). Project time–cost analysis under generalised precedence relations. *Advances in Engineering Software, 35*(10-11), 715-724.

Schwarze, J. (1980). An algorithm for hierarchical reduction and decomposition of a directed graph. *Computing, 25*(1), 47-57.

Siemens, N. (1971). A simple CPM time-cost tradeoff algorithm. *Management Science, 17*(6), B-354- B-363.

Siemens, N., & Gooding, C. (1975). Reducing project duration at minimum cost: A time-cost tradeoff algorithm. *Omega, 3*(5), 569-581.

Tareghian, H. R., & Taheri, S. H. (2006). On the discrete time, cost and quality trade-off problem. *Applied Mathematics and Computation, 181*(2), 1305-1312.

Vanhoucke, M. (2005). New computational results for the discrete time/cost trade-off problem with time-switch constraints. *European Journal of Operational Research, 165*(2), 359-374.

Xu, J., Zheng, H., Zeng, Z., Wu, S., & Shen, M. (2012). Discrete time–cost–environment trade-off problem for large-scale construction systems with multiple modes under fuzzy uncertainty and its application to Jinping-II Hydroelectric Project. *International Journal of Project Management, 30*(8), 950-966.

Yang, I. T. (2005). Chance-constrained time–cost tradeoff analysis considering funding variability. *Journal of Construction Engineering and Management, 131*(9), 1002-1012.

Yang, I. T. (2007). Using elitist particle swarm optimization to facilitate bicriterion time-cost trade-off analysis. *Journal of Construction Engineering and Management, 133*(7), 498-505.

Yang, I. T. (2011). Stochastic time–cost tradeoff analysis: A distribution free approach with focus on correlation and stochastic dominance. *Automation in Construction, 20*(7), 916-926. doi: 10.1016/j.autcon.2011.03.008.

Zhang, H., & Xing, F. (2010). Fuzzy-multi-objective particle swarm optimization for time–cost–quality tradeoff in construction. *Automation in Construction, 19*(8), 1067-1075.

Zhang, Y., & Thomas Ng, S. (2012). An ant colony system based decision support system for construction time-cost optimization. *Journal of Civil Engineering and Management, 18*(4), 580-589.

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