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The Use of Meta-Heuristic Methods to Solve Resource-Constrained Project Scheduling and Different Administrative Situations and Allowance to Cut Activities with Cut Costs

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ABSTRACT

This research presents a comprehensive modeling approach for the project scheduling problem, incorporating cut allowances and multiple administrative methods for each activity while accounting for earliness and tardiness costs. The model aims to optimize project timelines and minimize total cost by balancing the trade-offs between early and late task completion. To solve this complex scheduling problem, a genetic algorithm (GA) was developed and implemented. The performance and effectiveness of the proposed GA were evaluated through a series of computational experiments. For small-sized problems, results were compared against exact solutions obtained using LINGO software, demonstrating the algorithm's accuracy. For larger-scale problems, evaluation indicators such as solution quality and computational efficiency were employed to assess the GA's performance. The results indicate that the proposed algorithm consistently produces high-quality solutions within reasonable computational times, confirming its capability to handle both small and large problem instances effectively. Overall, this study provides a robust and efficient algorithmic framework for addressing complex project scheduling problems with multiple administrative options and earliness/tardiness cost considerations, offering practical guidance for project managers aiming to optimize project execution and resource allocation.

1. INTRODUCTION

We are looking for two main goals in project scheduling problems: 1) Estimation of project cost and attempts to minimize it. 2) To shorten duration and completion of project. These two goals both are in order to minimize costs, since economic justification of a project is its profitability. In simple and initial mood of such problems, there are numbers of activities defined with specified time and resources and a setting of prerequisite relations. These models are called RCPSP .but with development of these premium models, the ones more real and close to real world were proposed in which activities are defined by several run0-times considering different number of supplies instead of a specified time with fixed number of required resources. In these issues, selection of best time and best related

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resources (best mood) both are used to realize main goals; these models are called MRCPSP. Researchers also developed these models to propose new ones with interruption possibility in activities (P-MRCPSP). Interruption of activities means that they could be discontinued, while operating and after a time started again without any additional cost. In 1983, Blazvier et al proved that solving RCPSP problems with renewable resources is a NP-hard one, and since MRCPSP model is the developed mode of RCPSP model, it can be concluded that MRCPSP model and following it thee developed P-MRCPSP also are in range of NP-Hard problems; and we will need initiative and meta-heuristic methods solving them.

As it is observed, the point not considered in previous research but too much significant in the real world is cost availability per cut. This is an important point because it is no doubt that leaving a process in the middle of path and restarting will lead to lateral costs such as cost caused by relocation of equipment and machineries, corruption of perishable materials, and so on. In the current study, we consider this cost trying to minimize costs of earliness or tardiness of activities; in this regard, we will use meta-heuristic methods.

2. RESEARCH BACKGROUND

Shou [1] conducted a study called 'hybrid particles optimization for project scheduling in discontinuity mode'; the proposed model presents an optimization method for the group of hybrid particles in order to solve the problem of scheduling constraints in discontinuity mood. There were 4 types of particles presentation designed and also 2 schedules adopted to decode particles' display. The computational tests were performed on setting of standard design scheduling problems. The analysis of computational results confirms that prevention will help to decrease time plan, and also the methods proposed for group of particles are effective for project scheduling.

Clinas and Katsikaso [2] conducted research about 'mass particles optimization method based on exploratory algorithms: for projects' scheduling problems with constrained classic resources'; they indicated that this study uses mass particles optimization method based on exploratory algorithms for problem solving. This is the first attempt for PSO development and its utilization in RCPSPs. in fact, PSOs work as an algorithm with high level to control low level findings working for this important problem in solution environment. Active programs are made by a series of sequential programming shown through low level findings of this algorithm. Also, an optimization method is used for all solutions. The proposed method was tested in an environment with several important standards such as PSPLIB; also this method was compared with the ones in literature review. The presented computational results guarantee the efficiency of proposed method.

Afshar Najafi [3] proposed an approach to solve multiphase project scheduling problem with possibility of interruption and continuity of activities; that is a refrigeration simulation algorithm to solve proposed model. It showed algorithm efficiency to solve this type of issues and impact of interruption at the time of project completion. Van Hauk and Der proposed a genetic algorithm for project scheduling problem with multi-procedure methods which considers several administrative methods. They studied possibility of activity interruption as an innovation in scheduling problems with multi-phase administrative methods; they also studied cut effect on scheduling quality.

Sheikhi and Zahraie [4] conducted research called 'resource tabulation in construction projects considering the possibility to cut activities'; they expressed that their study includes an evolutionary optimization model in which the target function is formulized for resource tabulation in construction projects. In development of this optimization model, there are two options of activity discontinuity and activity relocation to achieve optimum mode of using resources during the project.

Discontinuity of activities means creating one or more pauses during the activity, and this process might be limited or banned for some activities; since it is not possible to cut activities in operations of some projects. The method suggested for resource tabulation uses floating activities (if available) to tabulate the fluctuations in resource usage; so that floating rate obtained by scheduling for each activity is used to change its execution time in schedule. This change is performed in terms of activity start up (relocation) or with a time pause (discontinuity) during the activity. After those considered changes was performed in activities of schedule, the histogram related to resources of new schedule is drawn. This process continues through single target algorithm to find an overall optimum answer. The optimum answer is obtained from target function related to each histogram produced in optimization levels. It is noteworthy that target function includes a setting of test functions; it provides the possibility of comparison of 'tabulated' results or 'optimum' histogram(s). The optimum answer shows a setting of activities in the schedule due to available limitations that will introduce most optimum mode of using resources during project. Finally, the codified model was implemented on a sample project to evaluate suggested method and to study the possibility of its application in real world. The results obtained by case study show the proper function of proposed model.

3. THE PROPOSED MODEL

Assume a project with AON network consists of 'n' activities marked from 1 to N. we consider the first and last virtual activities as start and stop points with zero duration and need for resources. Perquisite relations of the type $FS_0^{\min}$ are considered. It is possible to execute activities in different administrative moods, and each activity has specified delivery date that its deviation will result in penalties. Each activity is just capable of one executive mode, and it is not possible to change this mood during activity.

Parameters :

C_i : cut cost of activity i

α_i: earliness cost of activity i

τ_i: delay-charge of activity i

m_i: number of models in activity i

d_{im_i}: duration of activity i, if performed in mood m_i

r_{im_i}k: use of activity i, if performed in mood m_i of renewable k

R_k^P: maximum renewable resource of type k, accessible everyday

$r_{im_i}k'$: use of activity i, if performed in mood m_i of renewable k'

DD_i: delivery time of activity i

λ: large number

Variables:

X_{imit}: if activity I is performed at time t of mood m_i

Y_{im_i}: if activity is performed in mood m_i

Z_{imit}: if activity I has interruption at time t of mood m_i

$Smin_i$: start point of first part for activity i

$Smax_i$: start point of last part for activity i

E_i: earliness of activity i

T_i: delay-charge of activity i

There are three decision variables considered in the model presented here; thus, variable $x_{i,m_i,t}$ can possess one of values 0 or 1. It means that amount of this variable is equal to 1 if activity I would perform at time t in mood m, otherwise it is equal to 0. When Y_{im_i} possess value 1, it means that activity i would perform in moodm_i; at last, variable Z_{imit} is equal to 1 if activity i has interruption at time t in moodm_i.

$$\min F = \sum_{i=1}^{n} \sum_{m_i=1}^{|M_i|} \sum_{t=EST_i}^{LFT_{i-1}} C_i Z_{imi^t} + \sum_{i=1}^{n} (\alpha_i E_i + \tau_i T_i) \tag{1}$$

$$\sum_{m_i}^{|M_i|} X_{imit} \leq 1 \quad \forall i = 1, \dots, n, \quad t = EST_i, \dots, LFT_i - 1 \tag{2}$$

$$\sum_{t=EST_i}^{LFT_{i-1}} X_{imit} = d_{im_i} * Y_{im_i} \qquad \forall i = 1, \dots, n \qquad m_i = 1, \dots, |M_i| \tag{3}$$

$$\sum_{m_i}^{|M_i|} Y_{im_i} = 1 \quad \forall i = 1, \dots, n, \tag{4}$$

$$\sum_{i=1}^{n}\sum_{m_i}^{|M_i|} r_{im_i}\mathrm{k} * X_{imit} \le R_k^P \qquad \forall\, t = EST_i, \dots, LFT_i - 1, \qquad k = 1, \dots., k \tag{5}$$

$$\sum_{i=1}^{n}\sum_{m_i}^{|M_i|}\sum_{t=EST_i}^{LFT_{i-1}} r_{im_i}k' * X_{imit} \le R_{k'}^P \qquad \forall k = 1, \dots, k' \tag{6}$$

$$Smin_i \le t * X_{imit} + \lambda * (1 - X_{imit}) \quad \forall i, m_i, t \tag{7}$$

$$Smax_i \ge t * X_{imit}\ \forall i, m_i, t \tag{8}$$

$$Smax_i + 1 \le Smin_j\ \forall (i,j) \in A \tag{9}$$

$$E_i = max\{o, DD_i - (Smax_i + 1)\} \tag{10}$$

$$T_i = max\{o, (Smax_i + 1) - DD_i\} \tag{11}$$

$$\left|X_{imit} - X_{imit(t+1)}\right| = Z_{imit} \qquad \forall i = 1, \dots, n \quad m_i = 1, \dots, |M_i| \tag{12}$$

$$t = EST_i, \dots, LFT_i - 1$$

$$X_{imit}, Z_{imit}, Y_{im_i} \in \{o, 1\} \ \ \forall i = 1, \dots, n \quad m_i = 1, \dots, |M_i|$$

$$t = EST_i, \dots, LFT_i - 1 \qquad Smin_j, Smax_i, E_i, T_i \ \in \ int^+$$

Considering Z_{imit},Y_{im_i} and $x_{i,m_i,t}$ in the model above as decision variables for project scheduling problem, it expresses objective function attempting to minimize project costs including cut costs, earliness and delay-charge of activities. Constraint (2) guarantees performance of each part of activity 'i' at maximum one point (in each moment). Constraint (3) is length of each activity.

Constraint (4) guarantees performance of each activity exactly at one single mood. Constraints (5) and (6) are related to renewable and non-renewable resources, respectively. Constraints (7) and (8) are related to calculation of start point of first part and start point of last part both for activity i, respectively. Constraint (9) guarantees perquisite relations of activities; constraint (10) and (11) are related to calculation of earliness and delay-charge amounts both for activity i, respectively. And at last, constraint (12) relates to cut calculation of project activities; in other words, this constraint determines the point weather activity I has interruption at time't' or not.

4. PROBLEM SOLVING

In order to study the efficiency of designed genetic algorithm, there are 5 problems with little dimensions solved by genetic algorithm and Lingo software; then their results and solution times are compared. The problems solved by genetic algorithm are solved 5 times individually and average of best answer is calculated. The materials of problem solving were HP computer with core i5 cpu, 8 Gb of Ram, Lingo 14 software, and Matlab software version R2014b.

Table 1. Genetic algorithm efficiency in solving problems with small dimensions

Prob.	Number of activities	Number of moods	Renewable resources	Non-renewable resources	Lingo objective function	Time (s)	Objective function	Time (s)	Dev. Obj. (%)
1	10	3	2	2	137	52768	145	102	2.2
2	10	3	2	2	242	23592	251	98	5.5
3	10	3	2	2	156	58313	165	112	4.5
4	10	3	2	2	141	36296	149	105	3.6
5	10	3	2	2	104	61486	116	108	3.2

∗ Dev.obj. Shows deviation of answer obtained by algorithm from answer obtained by Lingo.

Since solving of big problems is not possible with software of exact solution (e.g. Lingo), we use two parameters to determine algorithm efficiency.

4.1. Relative percentage deviation (RPD)

This parameter helps us to compare efficiency of algorithms, because it shows the relative distance between answers and the best obtained answer of a specific example. It is obtained by the relation below:

$$RPD = \frac{OF_{algorithm} - OF_{best}}{OF_{best}} \times 100 \quad (13)$$

OFmin is amount of target function obtained by designed algorithm and Lingo software. $\mathrm{OF}_{\mathrm{algorithm}}$ is total expected cost for example and algorithm . Note that less amount of this parameter shows more efficiency of algorithm than Lingo software to solve little dimension problems .

4.2. Relative deviation index (RDI)

This parameter transform obtained results to numbers between 0 and 100; the obtained value by this parameter closer to 0, the more efficient is the algorithm. It is obtained by the relation below:

$$RDI = \frac{OF_{algorithm} - OF_{best}}{OF_{worst} - OF_{best}} \times 100 \quad (14)$$

$\mathrm{OF}_{\mathrm{best}}$ and $\mathrm{OF}_{\mathrm{worst}}$ indicate the best and worst answer obtained by proposed algorithm and Lingo software, respectively. Also $\mathrm{OF}_{\mathrm{algorithm}}$ shows value of d target function obtained by proposed algorithm or Lingo software.

Table 2. Genetic algorithm efficiency in solving problems with medium dimensions

Prob.	Number of activities	Number of moods	Renewable resources	Non-renewabl resources	Lingo objectiv fun.	Tim (s)	RPD	RDI
6	30	3	2	2	167113	226	1.78	70
7	30	3	2	2	163492	239	1.61	70
8	30	3	2	2	241834	237	0.48	70
9	30	3	2	2	232547	211	0.68	70
10	30	3	2	2	157146	200	0.53	70

4.3. Analysis of results

As it is observed, Lingo software wastes too much time obtaining optimum answer because of linearity of arithmetic model; but proposed genetic algorithm obtains appropriate answer in much less time than Lingo software. Thus, it can be concluded that proposed algorithm obtains proper answer quickly.

Table 3. Genetic algorithm efficiency in solving problems with large dimensions

Prob...	Number of activities	Number of moods	Renewable resources	Non-renewable resources	Lingo objective function	Time (s)	RPD	RDI
11	60	3	3	2	278421	695	3.43	88
12	60	3	3	2	270272	680	2.52	74
13	60	3	3	2	270664	667	1.22	73
14	60	3	3	2	272959	606	1.78	83
15	60	3	3	2	270415	659	0.91	89
16	60	3	3	2	273571	680	2.78	76
17	60	3	3	2	278239	710	3.01	81
18	60	3	3	2	268245	659	1.9	57
19	60	3	3	2	279013	695	2.5	83
20	60	3	3	2	267301	684	2.26	89

5. CONCLUSIONS

As mentioned before, there are two main goals for project scheduling problems: the estimated cost of project, and an attempt to minimize its duration and completion; these two goals both are typically in order to minimize costs since economic justification of a project is its profitability. the point not considered in the past studied but too much significant in the real world is the cost per each cut; This is an important point because it is no doubt that leaving a process in the middle of path and restarting will lead to lateral costs such as cost caused by relocation of equipment and machineries, corruption of perishable materials, and... Thus in this study, we consider this cost and trying to minimize it. The model proposed here was a non-linear arithmetic model; linear models are the strictest ones to be solved by exact solution software. Thus, a genetic algorithm was used to solve this problem, and finally in order to prove algorithm's capability solving mentioned problem, the results were compared with absolute and exact results by LINGO 14 software. Finally, it was shown that considering different administrative moods has a high impact on costs, project completion time, and usage of resources. On the other hand, it was shown that proposed algorithm has a very high level in terms of solution time and quality of results obtained. In practice, there might be some activities followed by a probability distribution function and/or could be expressed by Fuzzy method. We can study these problems in Fuzzy and probability conditions for further research: considering cut cost per number of days suspension, reduction in cost and time of project completion based on a two-objective model (cost and time), possible variability for activities after each cut and using meta-heuristic methods such as imperialist competitive algorithm or frog leaping algorithm solving the proposed problem.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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