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MULTI-PROJECTS SCHEDULING WITH RESOURCE CONSTRAINTS & PRIORITY RULES BY THE USE OF SIMULATED ANNEALING ALGORITHM

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Original scientific paper
This paper presents a hybrid genetic algorithm for assembly flow-shop scheduling problem with sequence-dependent setup and transportation times, with objectives, namely the minimizing of weighted, sum of total weighted squared tardiness, makespan, and total weighted squared earliness and number of tardy jobs. Since the problem is NP-hard, we solved this problem by hybrid genetic algorithm. To validate the proposed model, the Lingo 8.0 software is used. Comparison between the results of the Lingo 8.0 and hybrid genetic algorithm shows that in larger problems (if $n > 10$, where n is the number of jobs) the results obtained by Lingo do not have good efficiency and cannot be compared with the proposed hybrid genetic algorithm in terms of computational time and deviation from the minimum objective function. Test results are provided for a wide range of problem instances.

Keywords: *priority rules, project management, RCMPSP, scheduling, Simulated Annealing Algorithm*

Programiranje više projekata uz ograničena sredstva & Pravila prioriteta primjenom algoritma simuliranog žarenja

Izvorni znanstveni članak
Ovaj rad predstavlja hibridni genetski algoritam za problem programiranja kod montaže na tekućoj traci s vremenima podešavanja i prijenosa ovisnima o dijelu radne operacije, s ciljevima postizanja smanjenja ponderiranog, zbroja ukupnog ponderiranog kašnjenja na kvadrat, vremenskog intervala, ukupne ponderirane prijevremenosti na kvadrat i broja zakašnjenja. Budući da je problem NP-težak, riješili smo ga hibridnim genetskim algoritmom. Za provjeru predloženog modela korišten je softver Lingo 8.0. Usporedba između rezultata ovog softvera i hibridnog genetskog algoritma pokazuje da kod većih problema (ako je $n > 10$, gdje je n broj poslova) rezultati dobiveni softverom Lingo 8.0 nisu dovoljno učinkoviti i ne mogu se uspoređivati s predloženim hibridnim genetskim algoritmom u odnosu na vrijeme računanja i devijaciju od minimalne ciljne funkcije. Dani se rezultati ispitivanja za veliki broj rješavanih problema.

Ključne riječi: *algoritam simuliranog žarenja, pravila prioriteta, programiranje, upravljanje projektom, RCMPSP*

1 Introduction

Today, there is increasing benefit on project management for obtaining most organizational goals. Project management is used for finding some exceptional results by applying limited resources and within sensitive time limitations. Project scheduling is a base for supervising and controlling project activities and it is a major tool for project management. Most of the current scheduling methods of a project are applicable in scheduling of all activities of a single project with little submission of any methods or new method for scheduling of multi-projects activities [1].

Scheduling and allocation of resources for multi projects is somehow more difficult than single projects. There is a considerable increase in time limits for calculations in scheduling of multi projects or when there is a great scheduling problem. Therefore, any benefit from optimizing traditional methods would not be effective. Even if it is applicable, it would waste lots of time. As a result, the researchers go towards heuristic and meta-heuristic methods. Right now, there are lots of software packages for solving any scheduling problem of multi-projects. However, this software has different violations in providing the optimized answer against the major optimized reply. Also the researchers intend to find more efficient algorithms with more optimized answers [2]. There are different studies which are involved in the research such as increasing the efficiency of heuristic methods, extending the scope of solvable problems with heuristic methods, presenting new combined methods with higher calculation efficiency [3], The presented combined method of simulated annealing algorithm and famous RCMPSP rules in this paper is a new method for solving any problem of time scheduling. The proposed method has been tested with numerical examples along with comparing the results with famous rules of time scheduling. The obtained results make the priority of proposed method clearer than famous scheduling rules in all types of problems. Different types of scheduling techniques and project scheduling have been evaluated within the recent two decades and under limited resources condition [4]. We have used two methods for solving the problem of scheduling as follows: heuristic methods and Meta heuristic methods.

Heuristic methods are applicable for finding optimized solutions. But the mentioned methods are completely non-practical for great size problems and/or problems with great limitations. Some of the researches performed in this regard are included in references [5 ÷ 8].

Most people need to find a quick answer for project scheduling in great criterion in different industries. This case has involved most researches towards meta heuristic methods with a difference that meta heuristic methods could not generally find an optimized answer but may provide close answers to the optimized goal.

Due to the simplicity and suitable speed, priority rules are some of the most applicable methods for scheduling. There are lots of researches in the field of priority rules [9 ÷ 13].

Kim et. al applied a combined genetic algorithm for reasonable control of a phase and solving the scheduling problem in multi-purpose projects [14]. They intended to minimize total project time schedule and minimize any penalties for a general delay. Kumanan et al. presented a genetic algorithm with heuristic method for scheduling the problem of multi-projects and for minimizing the performance time of multi-projects [15]. In this essay there is a new framework for solving the problem of project scheduling in which a genetic algorithm is used for making priority of projects and from heuristic method for scheduling of different activities of projects.

Damak et al. combined a technical genetic algorithm with a local searching strategy without any violation of RCMPSP limitations in which the ideal function is total project delay and/or performance time of resources [16].

Goncalves et al. provided a simple genetic algorithm for scheduling in multi-projects [17]. This algorithm could minimize any tardiness, quickness and violation of current time simultaneously. The other works in the field of scheduling of multi-projects are as follows:

Jarboui et al. presented a hierarchical double level method including programming and scheduling procedures [18]. The programming steps were formulated in a linear program and scheduling step benefits from gradual annealing for calculation of the solution. Tormos and Lova developed integrated random sampling and coming/going innovations with the goal of average delay of project and increasing the performance term of multi projects [19].

Ghomi and Ashjari presented a simulation model for allocating any resources of multi-projects [20]. Vercellis explained the Lagrange analysis technique for solving programming problems of multi-projects with limitation of resources and different modes for performing of project activity [21].

All performed researches up to now reveal that there is not an applicable method for solving great and average problems. Therefore it is possible to consider the present research a new one accordingly [22].

2 Material and methods

Scheduling of various projects with limited resources includes two or more projects. Each project has a lot of activities with specific time schedules for performing activities and required resources. The real goal of scheduling the problem of multi-projects is to have the scheduling of all activities in a way to obtain any pre-determined goals with respect to all theories and limitations of the problem and pre-determined ideals [23]. Regarding all performed studies and considering the assumptions of previous multi-project scheduling essays, the following assumptions were considered for this problem:

- Projects are independent with regard to each other.
- It is possible for all projects to start simultaneously and need some common resources.
- Each activity will start after the end of its pre-requisite activities.
- It is not permitted to have any delay in performing the activities.
- There is a fixed and pre-determined period of time for performing the activities.
- Each activity has a performance condition and will be finished without any changes.
- We have access to a fixed amount of recyclable resources per day.
- The required resources of activities and their amount have been specified in the past.

2.1 Combined method

Combined method is a combination of Simulated Annealing Algorithm and Priority rules with a wide scope of application in the field of project scheduling. The general method of algorithm is to specify any priority of projects performance and the preliminary rule for scheduling different activities of a project. In this method we have simulated annealing algorithm for determining the priority of projects and benefiting from daily resources and selecting the best law from among the most famous priority rules and scheduling the activities in each project [24].

2.2 Priority rules

Priority rule may regulate a collection of permitted activities for a further scheduling process. Then it may allocate a priority for each permitted activity for further time scheduling. All applicable rules in this research have been extracted from the most famous priority rules of previous researches. Priority rules which are applied in this research have been displayed in Tab. 1. However, we did not use SASP, LALP, TWK-EST and TWK-LST rules due to their double-step situation in SA algorithm.

Also we did not apply RAN law because of creation of disorders in SA algorithm answers. Then by performing numerical tests it was revealed that the proposed algorithm benefited from four laws more than other rules in the solved examples. The mentioned rules are as follows: EDDF, MINSLK, MAXSP, MINWCS.

Table 1 Priority rules used in this research

Number	Rule	Number	Rule
1	FCFS	11	MCS
2	LCFS	12	MINTWK
3	EDDF	13	MAXTWK
4	MINLFT	14	MINWCS
5	SOF	15	WACRU
6	MOF	16	RAN
7	MINSLK	17	SASP
8	MAXSLK	18	LALP
9	MAXSP	19	TWK-EST
10	MS	20	TWK-LST

We applied these four laws instead of fifteen rules in the proposed method for reducing the space of answer and betterment of answers and reducing the solving term.

3 General Simulated Annealing algorithm

The general algorithm SA, which was introduced for the first time in 1953 by Metropolis, is as follows [25]:

```
Select an initial Solution a=a⁰ ∈ Sᵢ,
  Select an initial temperature T=T₀ ≻ 0,
Set temperature change counter t=0,
 Repeat Freezing Process,
        Set repetition counter i=0,
        Repeat - Equilibrium process
```

```
            Generate solution b: a neighbor or a,
                        Calculate Δf=f(a) -f(b) ,
            If (Δf ≻ 0) then a:=b ,
    Else if random (0, 1) ≺ exp (-Δf/t) then a:=b
i=i+1
Until i=N (t)
t:t+1 ,
T=T (t)
Until stopping criterion true
```

The general procedure of SA is shown in Fig. 1.

The main components of SA for implementation are as follows.

3.1.1 Creating the initial answer

In this program 1000 random answers by the length *h* were created and the answer with the best objective function was selected as the start point.

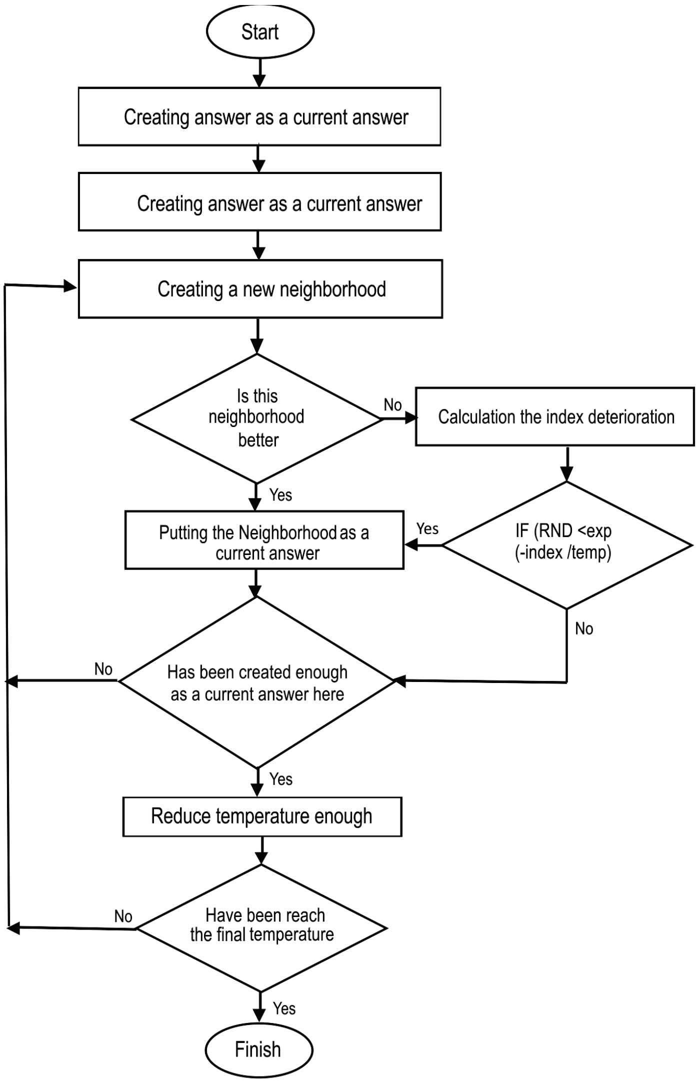

Figure 1 The general procedure of SA

3.1.2 Initial temperature

Temperature is one of the parameters that play an important role in the acceptance or rejection of the variation of the objective functions. Selecting initial value of temperature should be done in such a way that at the early stages, many undesirable answers should be selected. This is as a result of the possibility of the development and changes in the probability answer.

Actually, the initial temperature shows us how much we allow the probability answer to be deteriorated. It is more accurate to say how much each deterioration probability is accepted. The accepted probability of each deterioration answer is

$$e^{\frac{\text{-Index of deterioration the answer}}{\text{Temp}}}.$$

In order to be our index, almost independent of the problem size we should place it equal to

$$\frac{\text{Scale of deterioration the objective function}}{\text{Objective function}}.$$

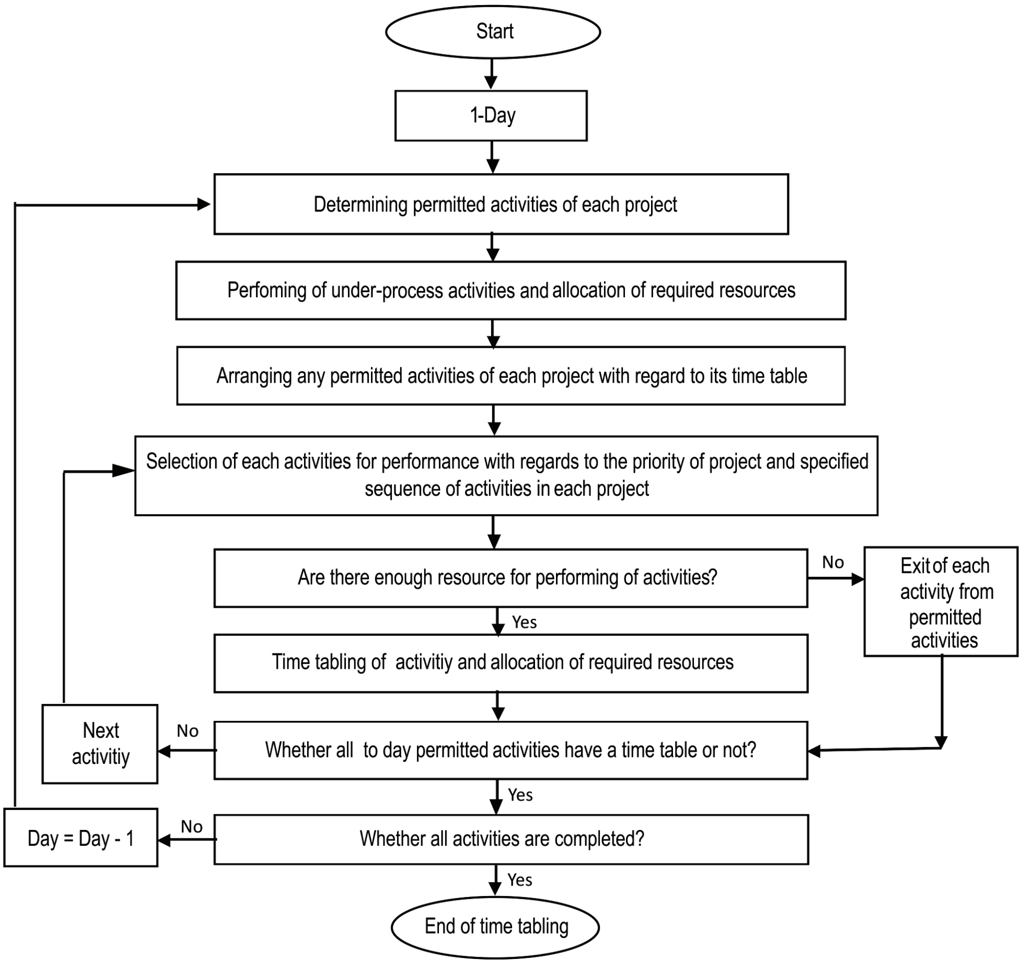

Figure 2 Project scheduling procedure

3.2 Determining the rate of temperature decrease

In order to reduce the probability of accepting the unfavorable answers, we should reduce the temperature. The way of changing this parameter is on the basis of the changes of the temperature functions $T_k = \alpha \cdot T_{k+1},\ \alpha \prec 1$ in this paper α = 0,95 is selected [27].

3.3 Determining the way of creating neighborhood

In this research we change two time units of H. If the functions get better, we can accept this relocation and if it deteriorates, we should find the size of deterioration of the objective function. We can find the index of deterioration of the objective function via the following equation [27]:

$$\frac{\text{Scale of deterioration the objective function}}{\text{Objective function}} =$$
$$= \text{Index of deterioration the objective function.}$$

And we produce a random number between 0 and 1 by uniform distribution.

If $e^{\frac{-\text{Index of deterioration the answer}}{\text{Temp}}} > \text{Rand}\ (0,\ 1)$, then we accept deterioration of the answer. If not, another neighborhood will be chosen.

3.4 Determining the number of neighborhoods which are reviewed in each temperature

In order to achieve better answers, more iteration is necessary. These iterations should be determined so that the run-time will be minimized and at the same time the answer must be favorable. In this research, the number of the iteration is constant and equal to1000.

3.5 Scale stop

The run-time of the calculation is dependent on the scale stop. It is important to know how effective this scale is in determining the favorite answer. The algorithm ends at the time the answers in each temperature do not change by increasing the temperature. This state is called freezing state. This status is assumed as the scale stop. In this research the final temperature assumed is 0,002.

4 Scheduling projects method:

In order to have a scheduling of project, we are faced with two sets of activities on daily basis: Under-process activities and Ready for scheduling activities.

Since it is not permitted to have any delay or stop in performing of activities, therefore firstly we have continuation of under-process activities which may use their required resources. Then we have ready for performance activities which may include different activities with considered pre-requisite limitations in case of enough resources. These steps will continue up to the completion of scheduling of activities in all projects and completion of under-process activities on daily basis. Fig. 2 shows all mentioned steps for this purpose.

4.1 Goal function

Goal function has been used for minimizing the project completion term in this research. This function is the most applied item in previous researches about scheduling of project. It is a sign of importance of this criterion in optimized scheduling of all activities in any projects. This criterion is used for scheduling of multi-projects as the greatest completion time of all projects.

5 Numerical example

There are 5 projects of 8-activity with permitted start and end activities. Project manager has no chance to provide scheduling for all five projects with regard to pre-requisite limitations and relevant resources. Figs. 3, 4, 5, 6 and 7 show the structure of each project network. Tabs. 2, 3, 4, 5 and 6 show the details of activities in each project including the performance term and required resources for each activity of project. There are 35 available resources in this organization for performing of all four-types of activities on daily basis. With such limitations, project manager has no chance to provide scheduling for this project in the best possible format and in compliance with organizational goals.

Table 2 Detail of project 1

Activity	1	2	3	4	5	6	7	8
Duration	0	1	3	4	5	2	2	0
Resource1	0	1	3	6	7	8	6	0
Resource2	0	9	7	8	5	4	0	0
Resource3	0	6	0	2	8	0	8	0
Resource4	0	10	7	1	2	2	9	0

Table 3 Detail of project 2

Activity	1	2	3	4	5	6	7	8
Duration	0	5	2	1	5	2	4	0
Resource1	0	10	8	6	8	10	4	0
Resource2	0	3	6	0	0	9	2	0
Resource3	0	7	8	3	0	9	6	0
Resource4	0	10	2	0	10	10	2	0

Table 4 Detail of project 3

Activity	1	2	3	4	5	6	7	8
Duration	0	4	4	2	3	4	5	0
Resource1	0	10	0	0	9	5	2	0
Resource2	0	5	3	8	5	0	6	0
Resource3	0	3	0	3	2	0	0	0
Resource4	0	0	6	6	10	4	0	0

Table 5 Detail of project 4

Activity	1	2	3	4	5	6	7	8
Duration	0	2	3	2	3	1	3	0
Resource1	0	4	0	9	0	8	0	0
Resource2	0	8	4	2	7	9	10	0
Resource3	0	9	1	7	3	6	0	0
Resource4	0	0	9	0	0	6	3	0

Table 6 Detail of project 5

Activity	1	2	3	4	5	6	7	8
Duration	0	2	1	1	5	5	1	0
Resource1	0	0	0	0	2	0	0	0
Resource2	0	8	2	0	8	1	4	0
Resource3	0	0	8	8	0	0	0	0
Resource4	0	0	0	3	0	0	7	0

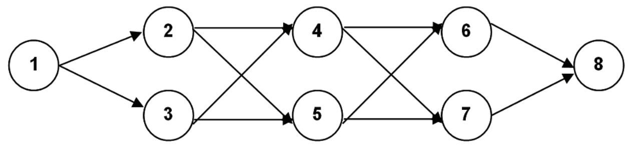

Figure 3 Network project 1

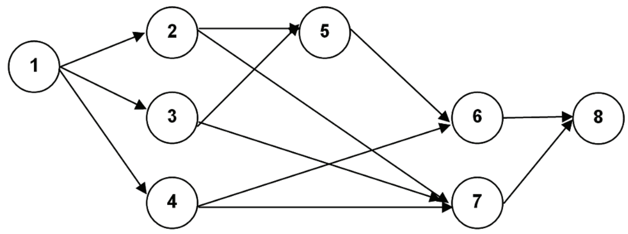

Figure 4 Network project 2

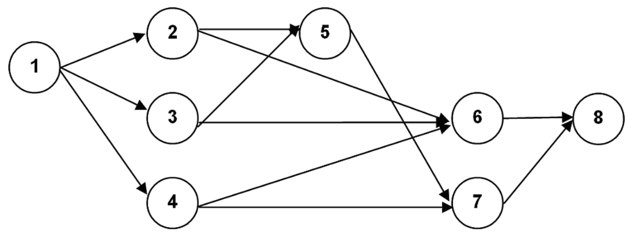

Figure 5 Network project 3

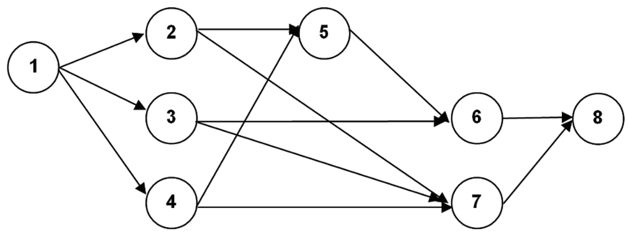

Figure 6 Network project 4

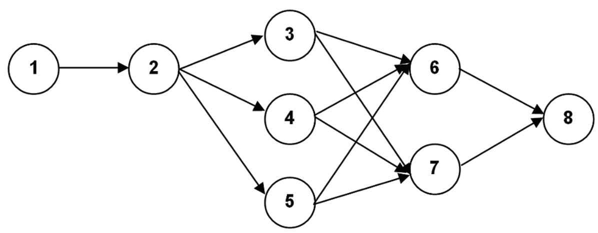

Figure 7 Network project 5

Fig. 8 shows the obtained scheduling by the proposed method. Fig. 9 shows all comparison between the obtained scheduling and proposed method and the most applicable rules of scheduling of project. As it is clear in Fig. 9, the proposed method has a better response against 20 rules of scheduling of project.

	Project 5	Project 3	Project 2	Project 1	Project 4
Day 1 >>	*234****	*234****	*23*****	*2******	********
Day 2 >>	*2******	*234****	*23*****	********	********
Day 3 >>	****5***	*23*****	*2******	********	********
Day 4 >>	****5***	*23*****	*2******	**3*****	*2******
Day 5 >>	****5***	****5*7*	*2*4****	**3*****	*2******
Day 6 >>	****5***	****5*7*	****5***	**3*****	**34****
Day 7 >>	****5***	****5*7*	****5***	********	**34****
Day 8 >>	*****6**	*****67*	****5***	***45***	**3*5***
Day 9 >>	*****6**	*****67*	****5***	***45***	****5***
Day 10 >>	*****6**	*****67*	****5***	***45***	****5***
Day 11 >>	*****6**	*****6**	*****67*	***45***	*****67*
Day 12 >>	*****6**	********	*****67*	****5***	******7*
Day 13 >>	******7*	********	******7*	*****67*	******7*
Day 14 >>	********	********	******7*	*****67*	********

The maximum time requested to schedule all the 5 projects with resource constraint IS=14 days

Figure 8 Scheduling of multi-projects produced by proposed method

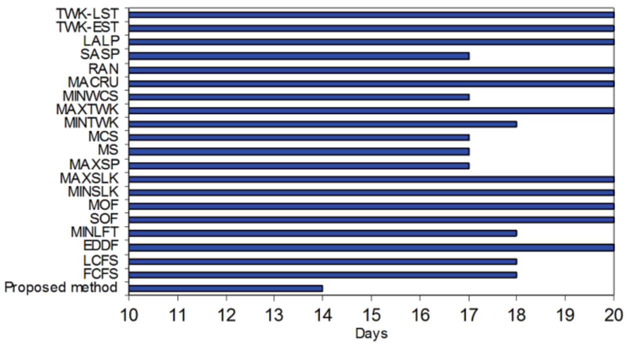

Figure 9 A comparison between scheduling produced by proposed method and most applicable rules in project time scheduling

6 Results

In this section, twelve (12) experimental issues for optimizing completion time of multi-projects scheduling with resource constraints and the priority rules in different dimensions that were produced randomly were done by SA. A Personal Computer (PC) of 3.2PIV, 2 GB RAM was used and the program applied is MATLAB 7.5. The results of the experiments are shown in Tab. 7.

Table 7 The result of experiments by the use of simulated annealing in different dimensions

Problem name	Number of projects	Number of activities	Computational time	Best answer
Vmd1	5	8	0:00:27	14 days
Vmd2	5	20	0:00:41	18 days
Vmd3	10	10	0:00:52	21 days
Vmd4	10	20	0:01:28	25 days
Vmd5	30	30	0:02:49	62 days
Vmd6	30	50	0:03:36	68 days
Vmd7	40	50	0:04:02	79 days
Vmd8	40	60	0:04:16	145 days
Vmd9	100	125	0:06:11	169 days
Vmd10	100	150	0:07:01	251 days
Vmd11	150	200	0:09:06	348 days
Vmd12	200	250	0:10:22	526 days

7 Parameter setting

In this section, the results of the computational experiments were used to evaluate the performance of the proposed algorithm for optimizing completion time of multi-projects scheduling with resource constraints and priority rules. There were twelve (12) instances for each problem. At this point, some information about parameter analysis would be useful. Initially, several experiments were conducted on test problems in order to determine the tendency for the values of the parameters to be suitable for the experiment. Six test problems were used for this purpose [26].

In each step, only one of the parameters was tested. Each test was repeated four times. We considered the following values for the several parameters required by the proposed SA:

- Initial Temperature (IT): four levels (1,0; 0,90; 0,80 and 0,75).
- Temperature Decrease Rate (TDR): four levels (0,02; 0,04; 0,05 and 0,08).
- Final Temperature (FT): three levels (0,001; 0,002 and 0,005).
- Number of Iteration in each Temperature (NIT): one level (1000).

Test results showed that these values were suitable for the problem. Later, additional tests were conducted in order to determine the best values. After completing the tests, Taguchi analysis was applied for the different values of parameters. The best values of the computational experiments for optimization of completion time of multi-projects scheduling with resource constraints & priority rules obtained for IT = 0,95; TDR = 0,04; FT = 0,002 and NIT = 1000. These values were set as the default value of the Parameters.

8 Conclusion

There are lots of researches on project time scheduling; however, all the researches were carried out on single or multi-projects. This paper presents a combined method of simulated annealing algorithm and the best priority rules for solving the problem of scheduling in multi-projects with the goal of minimizing the project performance time. For this purpose the structure of the proposed algorithm and applicable rules is specified in this method. Then we compared the efficiency of the combined method with the best results out of priority rules. According to the findings, the combined method had better results than multi-purpose rules of time scheduling. For future researches, it is proposed that researchers should consider the function of other goals such as current cash flow, delay costs, etc. and the combination of the proposed method with other local research methods, considering the problem in an active situation.

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