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A Taghuchi based Multi Objective Time-Cost Constrained Scheduling for Resource Availability Cost Problem: A Case Study

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A B S T R A C T

In this paper, a new multi-objective time-cost constrained resource availability cost problem is proposed. The mathematical model is aimed to minimize resource availability cost by considering net present value of resource prices in order to evaluate the economic aspects of project to maximize the quality of project's resources to satisfy the expectations of stakeholders and to minimize the variation of resource usage during project. Since the problem is NP-hard, to deal with the problem a simulated annealing approach is applied, also to validate our results GAMS software is used in small size test problems. Due to the dependency of SA algorithm to its initial parameters a taghuchi method is used to find the best possible SA parameters combinations to reach near optimum solutions in large size problems.

Keywords: Constrained project scheduling, resource availability cost problem, simulated annealing algorithm, metaheuristic algorithms.

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1. Introduction

Resource constrained project scheduling is a widely-investigated topic during last decades with a host of application in industry which is an intricated problem to solve. The main idea of RCPSP is to schedule a set of activities in view of resource and precedence constraints. Resource availability cost problem (RACP) derives from RCPSP with aim of minimizing the renewable resource costs by considering the project deadline [1]. Möhring [2] presented RACP first time and proved that RACP is NP-hard.

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There are many researches about RCPSPC problem. Hartmann [3] suggested a new GA for solving RCPSP with the objective of minimization the makespan. He pointed out that their GA had better performance rather than other approaches up to that time. Bouleimen and Lecocq [4] used simulated annealing (SA) algorithm for RCPSP with the objective of minimization the makespan. Brucker [5] introduced machine scheduling problem related to RCPSP and discussed about heuristic and branch and bound methods in order to solve the problem with the objective function of minimizing project completion time. Li and Womer [6] developed a dynamic programing to solve stochastic RCPSP. Ma et al. [7] proposed a URCPSP with uncertain durations.

Vanhoucke and Coelho [8] suggested a new solution for RCPSP considering three types of constraint; their objective was to minimize the total project makespan. Yassine et al. [9] suggested two new GA approaches for scheduling the activities of project with the objective of minimizing the overall duration of the portfolio. Kreter et al. [10] extended the RCPSP with general temporal constraints using concept of break-calendars. They proposed three version of scatter search to solve problem heuristically with objective function of minimizing the makespan. Drexl and Kimms [11] point out the solution of RACP for several deadlines. They also proposed two lower bound procedure for RACP.

Yamashita et al. [12] considered a project scheduling problem with objective of minimizing resource availability costs. They used scatter search to tackle the problem and compared the optimal solution achieved by cutting plane algorithm with upper and lower bound for small instances. Yamashita et al. [13] presented a project scheduling problem with resource availability cost by taking into account the durations as uncertain variables and proposed scatter search based method to deal with the problem. Ranjbar et al. [14] considered a project scheduling with the objective of minimizing resource availability cost and developed two metaheuristics (path relinking and genetic algorithm) to find a suitable solution. Van Peteghem and Vanhoucke [15] suggested an artificial immune system (AIS) algorithm for the resource availability cost problem. Rad et al. [16] provided a model for program scheduling regarding the resource constraint. The objective is to minimize the completion time, cost, and maximize net present value, they also applied gams to deal with the model.

In this paper, a RACP model is developed to minimize the resource availability cost considering net present value of costs, minimize the variations of resources during the project lifetime and maximize the quality of project to meet the stakeholder's expectation. To maximize the quality of project we should use more amount of financial resources while other objectives are included to the model for minimizing the costs and lack of resources. To the best of our knowledge this the first research that deal such objective functions in RACP considering budget constraint.

The rest of the paper is organized as follows: Problem description and mathematical formulation are presented in Section 2. Section 3 presents the developed meta-heuristic solution algorithms. Section 4 handles the computational results and sensitivity analyses. Finally, the paper concludes is provided in Section 5.

Table1. Overview of the literature on RCPSP and RACP problem.

Features / Pape	NPV	QUALITY	BUDGET CONST	UNCERTAINTY	RACP	RCPSP	METHOD
[1]	×	×	×	×	✓	×	heuristic
[6]	×	×	×	✓	×		ADP algorithm
[17]	×	×	×	✓	×	✓	GA
[18]	×	×	×	×	×	✓	Scatter search-priority rule method
[15]	×	×	×	×	✓	×	AIS
[16]	✓	✓	×	×	✓	✓	Numerical example solved by gams
[19]	×	✓	✓	×	×	✓	e-constraint method
This study	✓	✓	✓	×	✓	×	SA

2. Model Description

In the proposed model, V is assumed as the set of activities, Activity 1 and n are dummy activities that are the start and finish time of the project. Edge $(i, j) \in$ E, depicts the precedence relation between activities. Resources set is denoted by M and duration of each activity in the project is shown by d_j. c_k is the unit cost of k-th resources used during the project for activities. r_k^j is the unit resources that is required for activity j. Variables ef_{tj} and lf_{tj} are earliest finish and latest finish time of denoted activity. Let, $\overline{r_k}\ be\ \sum_{j=1}^{v} {}^{1}\!/_{v}\, r_k^j$, as the average usage of k-th resource during the project. $a_k(t)$ is the usage of k-th resource during the (t-1, t) period and A_k is the max $of\ \{a_k(t)\ \ t = 1 \ldots H\}$. Resource availability cost of project is demonstrated by C(A). $\mathcal{Z}_{\mathrm{k}}^{\mathrm{PIS}}$ and $\mathcal{Z}_{\mathrm{k}}^{\mathrm{NIS}}$are the negative and positive ideal solution for each objective function, respectively and q_{jk} is the quality of k-th resource assigned to the activity j.

$$min \sum_{j\in v} \sum_{k\in m} \sum_{t=ef_{tj}}^{t=lf_{tj}} c_k e^{-\alpha t x_t^j} \quad A_k \tag{1}$$

$$min \sum_{k\in m} \sum_{j\in v} \left(r_k^j - \bar{r}_k\right)^2 \tag{2}$$

$$\max \sum_{k\in m} \sum_{j\in v} q_{jk} y_{jk} \tag{3}$$

s.t.

$$\sum_{t=ef_{tj}}^{t=lf_{tj}} x_t^j = 1 \quad \forall i \tag{4}$$

$$\sum_{t=ef_{tj}}^{t=lf_{tj}} t x_t^j - \sum_{t=ef_{ti}}^{t=lf_{ti}} t x_t^i \geq d_j \quad (i.j) \in E \tag{5}$$

$$\sum_{t=ef_{ti}}^{t=lf_{ti}} x_t^1 = 0 \tag{6}$$

$$\sum_{t=ef_{tn}}^{t=lf_{tn}} t x_t^n \leq D \tag{7}$$

$$A_K \geq \sum_{j\in v} r_k^j \, x_t^j \quad \forall k \tag{8}$$

$$\sum_{k\in m} \sum_{j\in v} q_{jk} c_k \leq C_{total} \tag{9}$$

The first objective of project describes the resource availability cost considering net present value of prices while second objective is aimed to level the usage of resources during the activities time. Third objective function maximizes the quality of resources in order to increase the stakeholder's satisfaction. Constraint 4 makes all the activities to complete between their late and early finish period. Constraint 5 considers the precedence relation between the activities. Constraint 6 shows that the start time of project is zero. Constraint 7 denotes the deadline of project. Constraint 8 determines that the resource availability of *k*-th resource type is lower or equal to its maximum usage. Constraint 9 shows the budget limitation.

3. Solution Representation

Since the problem is multi objective and NP-hard and proposed research in Section 1 proves it, a metaheuristic approach is illustrated to deal with the problem. Many approaches are introduced to deal with the multi objective problems such as weighted sum, goal programming, and goal attention. In this paper, a TH method is used; the steps of the TH method can be summarized as follows [20]:

Step 1: Set a negative and positive Value for each objective as (NIS) and (PIS).
Step 2: Determine function for each objective function as Eq. (10) for objective functions desired to be minimized and as Eq. (11) for the objective functions desired to be maximized.

$$\mu_k(\mathcal{Z}) = \begin{cases} 1 & \text{if } \mathcal{Z}_k < \mathcal{Z}_k^{PIS} \\ \dfrac{\mathcal{Z}_k^{NIS} - \mathcal{Z}_k}{\mathcal{Z}_k^{NIS} - \mathcal{Z}_k^{PIS}} & \text{if } \mathcal{Z}_k^{PIS} \leq \mathcal{Z}_k \leq \mathcal{Z}_k^{NIS} \\ 0 & \text{if } \mathcal{Z}_k > \mathcal{Z}_k^{NIS} \end{cases} \tag{10}$$

$$\mu_k(\mathcal{Z}) = \begin{cases} 1 & \text{if } \mathcal{Z}_k < \mathcal{Z}_k^{PIS} \\ \dfrac{\mathcal{Z}_k - \mathcal{Z}_k^{NIS}}{\mathcal{Z}_k^{PIS} - \mathcal{Z}_k^{NIS}} & \text{if } \mathcal{Z}_k^{PIS} \leq \mathcal{Z}_k \leq \mathcal{Z}_k^{NIS} \\ 0 & \text{if } \mathcal{Z}_k > \mathcal{Z}_k^{NIS} \end{cases} \tag{11}$$

Step 3: In order to convert the multi-objective model into a single-objective one by means of the TH aggregation function. It should be noted that the TH method guarantees to get the efficient solutions [21]. The TH aggregation function is computed by:

$$\text{Max } \psi(X) = \vartheta\lambda_0 + (1-\vartheta)\sum_k \varphi_k \mu_k(\mathcal{Z}) \tag{12}$$

s.t.

$$\lambda_0 \leq \mu_k(\mathcal{Z}) \; k = 1, 2, 3 \tag{13}$$

$$x \in F(x) \qquad \lambda_0.\psi \in [0,1] \tag{14}$$

$$\sum_k \varphi_k = 1. \tag{15}$$

Where, $F(x)$ signifies the feasible region. Furthermore, ϑ and φ_k ($\sum_k \varphi_k = 1$) are the coefficient of compensation and the importance of the k-th objective function, respectively. In this way, the DM can achieve a compromise solution between the minimum of the objective functions and the weighted sum of the objective functions.

Step 4: Solve the single-objective model. If the DM is satisfied with the gained compromised solution, stop; otherwise, change the values of parameters to obtain another solution.

3.1. Simulated Annealing

Verbeeck et al. [22] suggested a meta heuristic framework of the artificial immune system for the constrained project scheduling. In their investigation, the completion time of project was on time and they minimized the total additional cost for the resources. Van Peteghem and Vanhoucke [23] proposed an Invasive Weed Optimization (IWO) algorithm for RACP. The total cost of the renewable resources needed to finish project was minimized. IWO is inspired by natural behavior of weeds in discovering an appropriate place for growth and regeneration. Eshraghi [24] presented an algorithm for solving RCPSP. He proposed a different evolution algorithm and added local search to enhance the performance of an algorithm. He compared the result with GA. Alhumrani and Qureshi [25] solved RCPSP considering GA. The objective of this paper was to optimize the completion time of project regarding limitation in resource. The

GA was used to solve multiple resource constraints. Bilolikar et al. [26] have used GA for the global search and SA for local search. They have considered discounted cash flow in RCPSP.

Simulated annealing belongs to a class of local search algorithms that are introduced as threshold algorithms. These algorithms play significant role within local search because of two reasons. The first reason is they appear to be successful when applied to a broad range of practical problem and second reason is about some threshold algorithms such as simulated annealing which has a stochastic component and this has made them popular to mathematicians.

SA algorithm repeats an iterative neighbor generation procedure and follows search directions that enhance the value of the objective function. Whilst investigating solution space, the SA method suggests the possibility to confirm worse neighbor solutions in a controlled manner in order to escape from local minimum. Totally, in each iteration, for a current solution x characterized by an objective function value f (x), a neighbor x' is selected from the neighborhood of x indicated N(x), and defined as the set of all its immediate neighbors. For each move, the objective difference $\Delta = f(x') - f(x)$ is assessed. For minimization problems x' substitutes x whenever $\Delta \leq 0$. Otherwise, x'could also be confirmed with a probability $P = e^{(-\Delta)/T}$. The acceptance probability is compared to a number $y_{random} \epsilon [0.1]$ generated randomly and x' is accepted whenever P >y_{random}. The factors that influence acceptance probability are the degree of objective function value degradation Δ (smaller degradations induce greater acceptance probabilities) and the parameter T called temperature (higher values of T give higher acceptance probability). A cooling scheme specifying can control the temperature by how it should be progressively reduced to make the procedure more selective as the search progresses to neighborhoods of good solutions.

A typical finite time implementation of SA consists in decreasing the temperature T in S steps, starting from an initial value T_0 and using an attenuation factor α 0 < α < 1. The initial temperature T_0 is supposed to be high enough to allow acceptance of any new neighbour proposed in the first step. In each step s, the procedure produces a fixed number of neighbor solutions N_{sol} and evaluates them using the current temperature value $T_S = \alpha^S T_0$. The whole process is called ‘‘cooling chain’’ or also ‘‘markov chain’’

Indeed, the SA algorithm begins from a very high temperature where solutions can move to far distances without any sense of direction and speed limitation. Such movements permit SA to look for larger areas in solution space to find better areas. While cooling process continues, the solutions visit closer neighbors in more reasonable direction that help to search more deeply a suspected area. This high speed of convergence may cause falling in local optimum trap. To reach to the optimal solution we have done random permutation as shown in Figure 1. As this permutation did not consider the limitation such as prerequisite and relations, we have had infeasible solution. To generate feasible solution, we have used Floyd-War shall algorithm. This algorithm is one of the most popular algorithm to find the shortest path between every two nodes and it will provide feasible solution, considering this algorithm as the central computational core of genetic algorithm has made this procedure to a hybrid one. In order to better description, we will describe the repair mechanism of schedule programming:

step 1. Select the first activity remained.
step 2. If selected activity can be done add it to new list.
step 3. Otherwise, select another activity in an old list then repeat Step 2.

3	7	4	2	5	8	6

3	2	4	7	5	6	8

Figure 1. Production initial solutions and repairing of solutions.

3.2. Taguchi Method

As an approach of factorial design of experiments, TM aims to improve the quality of manufactured processes. A full factorial experiment is an experiment whose design includes two or more factors, each with discrete possible values or 'levels', and whose experimental units take on all possible combinations of these levels across all such factors; i.e. an experiment will consider all possible combinations for a given set of factors [27]. In order to increase the number of experiments and achieve a good combination of parameters to run the Simulated annealing Taguchi's signal-to-noise (S/N) is used. Table 2 Shows the levels of SA factors. The simulated annealing is comprised of two external and internal iteration respectively, alpha is the decreasing rate of temperature and shows the speed of investigating different solutions and initial temperature acts like a beginning point for the start of algorithm, each of which are considered in three level achieved by previous researches. Figure 2 demonstrates the result of Taguchi method achieved by MINITAB 17. This figure shows the optimal level of each factor for this problem, which is 200 for maximum iteration, 40 for inner iteration, 0.94 for alpha and 10 for initial temperature.

Table 2. Design factors and their levels.

	Levels		
parameters	1	2	3
Maximum iteration	100	150	200
Inner iteration	20	30	40
Alpha	0.9	0.94	0.94
Initial temperature	5	7	10

Figure 2. Taguchi's signal-to-noise (S/N).

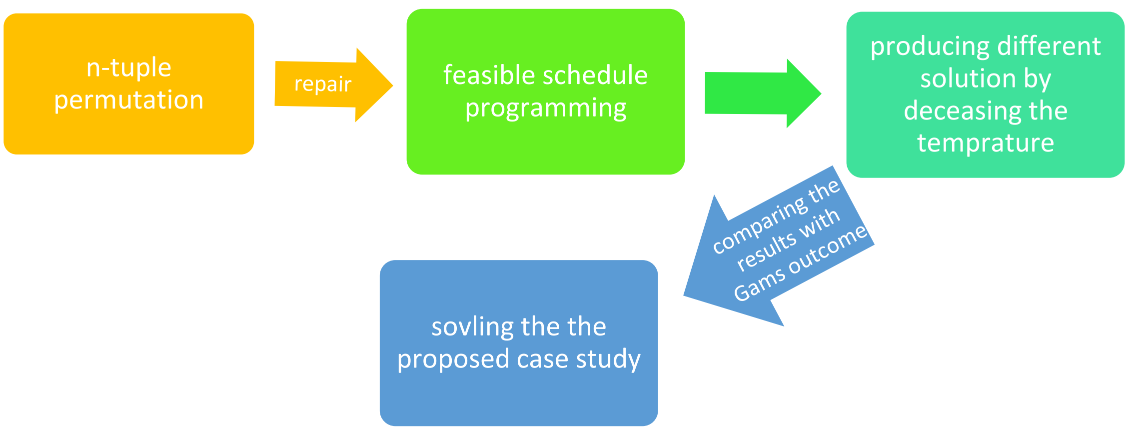

Figure 3. Overall process of solutions review.

4. Computational Results

In this section, in order to validate the obtained answer and assess them, different small size test problems are generated and compared with the results of coded model in GAMS 24.7. In addition, the results of proposed case study are described as follow. In this paper, a 28-storey office tower under construction located in west of Tehran including 500 human resources is reviewed. Based on project data's and comments of experts the Distribution functions of randomly generated problems are depicts in Table 2. In order to deal with the real case study, all the activities are summarized in main groups, which is shown in Figure 3. In addition, resources are categorized in four major groups. First group belongs to building resources such as cement, concrete and beams, second group comprises of electrical elements, third group comprises of mechanical resources and last group has covered decorations and safety equipments. The main activities of proposed case are shown in Table 3. To validate the results of SA algorithm, the results of which are compared with GAMS results in small size problems as$\left[100 \times \left(\mathrm{G_{Opt}} - \mathrm{G_{Alg}}\right)/\mathrm{G_{Alg}}\right]$, where

G_{Opt} and G_{Alg} are the TH objective function value obtained from GAMS software and developed algorithm, respectively. The activities of this project are summarized to 20 activities for simplicity of problem, which are shown in Table 3. However, to show the performance proposed algorithm, large size test problems are included in result table. In addition, sensitivity analysis results for a test problem with 14 activities and 2 resource group are shown in Figure 4. Table 4 demonstrates the results of each objective function by considering $(\varphi_k = (0.7.0.2.0.1).\alpha = 0.3)$ and different test problems, which proves the feasibility of each objective, function along with the rest of constraints. Table 5 shows the results of weighted sum single objective problem in different scales, this table shows a compromise answers between objective functions with different directs. Figure 6 depicts the results of weighted sum single objective problem with different objective function coefficients. It should be mentioned that in these tables and figures OFV stands for objective function value.

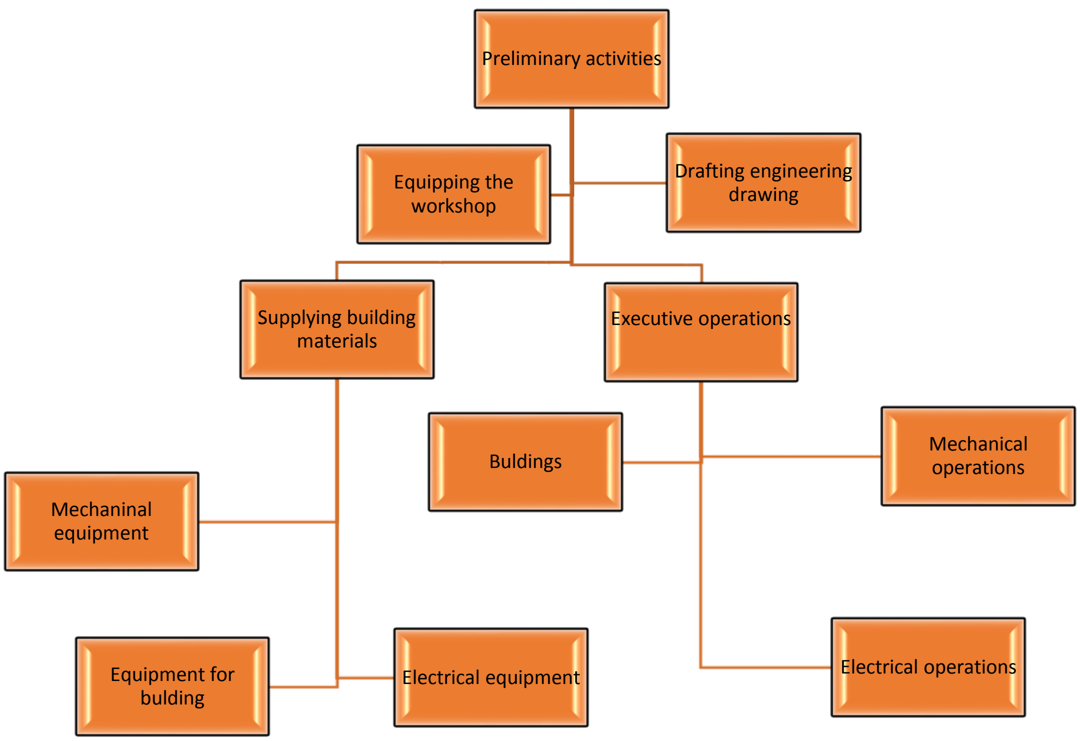

Figure 4. Summarized work break down structure of proposed project.

Table 4. Main activities of proposed case.

Activity Number	Activity Name
1	Preliminary Activities
2	Equipping the Work Shop
3	Drafting Mechanical Drawing
4	Drafting Electrical Drawing
5	Electrical Equipment
6	Mechanical Equipment
7	Decorations and safety Equipment
8	Building Resources
9	Building of first cluster
10	Building of second cluster
11	Building of third cluster
12	Joinery Building of first cluster
13	Joinery Building of second cluster
14	Joinery Building of third cluster
15	Setup electric installations of first cluster
16	Setup electric installations of second cluster
17	Setup electric installations of third cluster
18	Setup Mechanical installations of first cluster
19	Setup Mechanical installations of second cluster
20	Setup Mechanical installations of third cluster

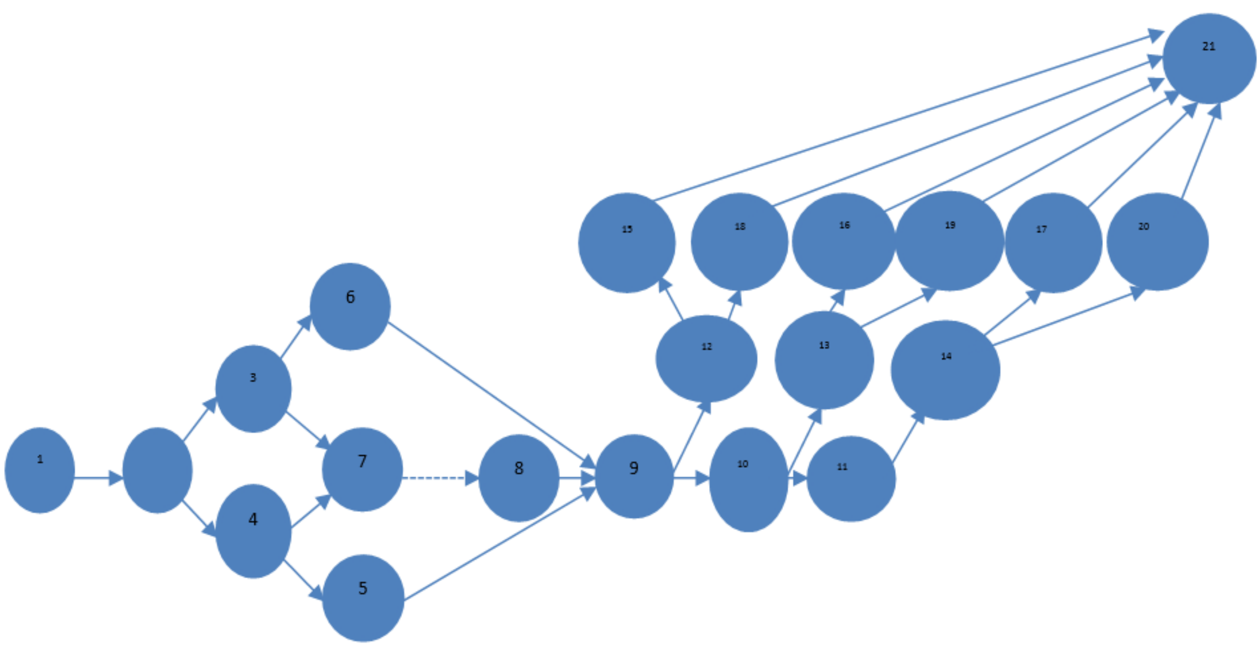

Figure 5. Gant chart of proposed project.

Table 5. Objective functions vs. alteration of $(\varphi_k = (0.7.0.2.0.1).\alpha = 0.3)$.

Data set	V	k	OFV1	OFV2	OFV3
1	10	2	678942	9010	67911
2	14	2	718343	14000	70081
3	20	2	953451	15010	74012
4	30	2	1356782	18101	79562
5	40	2	1634567	20318	84095
6	10	4	1045681	13411	74321
7	14	4	1178654	16345	76554
8	20	4	1345678	19845	79001
9	30	4	1565478	21901	83215
10	40	4	1823456	24104	85321

Table 6. Average objective function and CPU Time for test problems $(\alpha = 0.3)$.

		SA			
Data set	V	k	OFV	Time	GAP
1	10	2	0.765	45	0.66%
2	14	2	0.962	60	0.79%
3	20	2	1.023	87	1.11%
4	30	2	1.201	121	NA
5	40	2	1.3	173	NA
6	10	4	1.09	143	NA
7	14	4	1.1	163	NA
8	20	4	1.23	198	NA
9	30	4	1.321	234	NA
10	40	4	1.401	251	NA

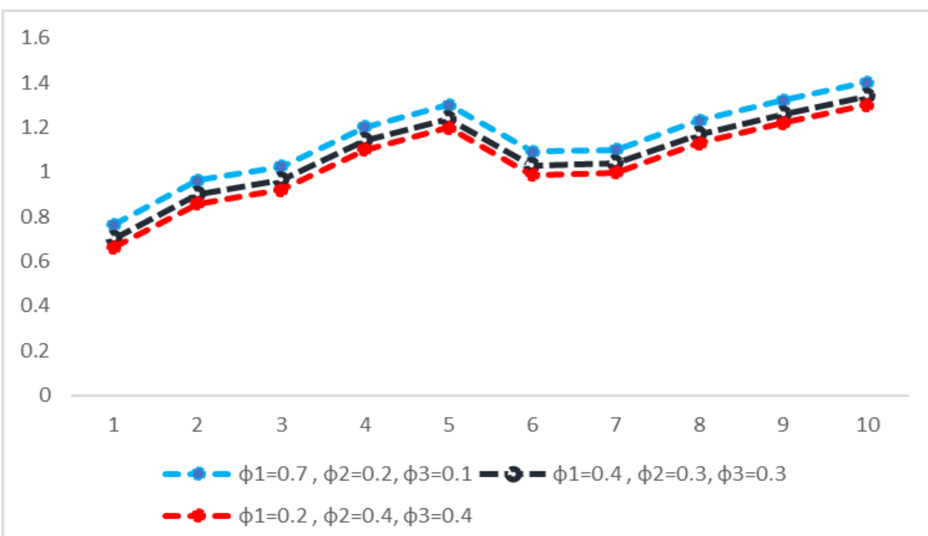

Figure 6. Comparison of obtained average objectives by fluctuations of objective function coefficients.

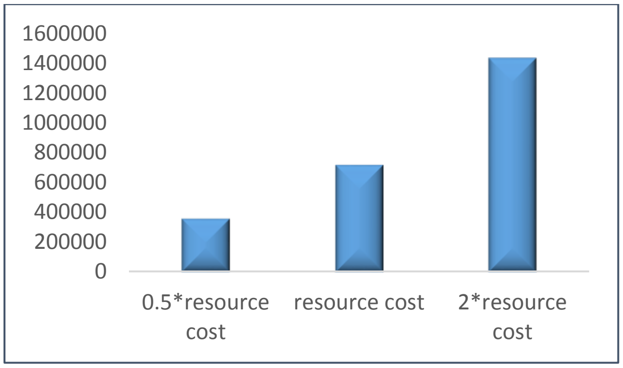

Figure 7-a. OFV vs. different resource cost confidence levels.

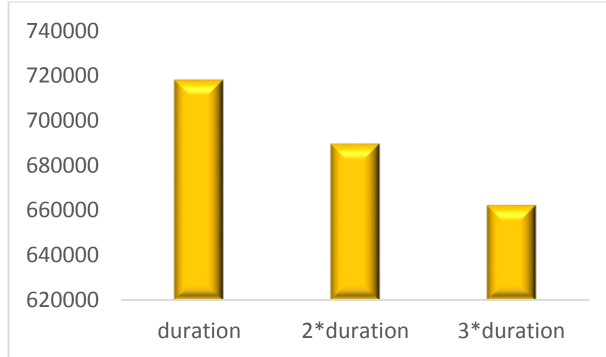

Figure 7-b. OFV vs. different duration confidence levels.

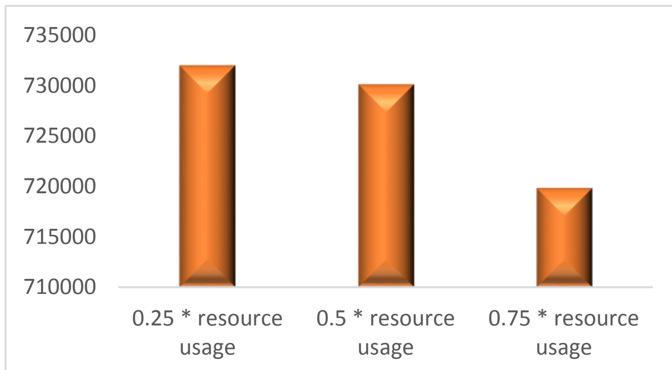

Figure 7-c. OFV vs. different resource usage confidence levels.

5. Conclusions

In this paper, a novel Non-linear multi objective model proposed which aim is to increase the quality of project that leads the satisfaction of beneficiaries. It also minimizes the availability cost and variation of resources. Since the contradictions between the Quality, Time and Budget is a big challenge in real problems this model is able to guide the decision makers to select the better options considering different aspects of a real case. Results of Table 6 validates the grasp results of SA algorithm compared with the Gams. Thus, different sensitivity analysis, which are able to assess the reaction of results by changing the various crucial parameters such as duration, resource usage and resource price are shown in Figure 6 and Figure 7. Future research can consider a development in the suggested framework. For instance, they should focus on the extension of RACP, considering some other limitation to close the real life. It also seems beneficial using the suggested algorithm to other resource availability cost problem in practical applications. Numerous techniques to improve the performance of presented meta-heuristic can be considered.

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