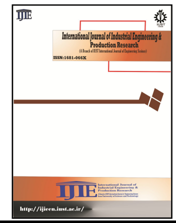
International Journal of Industrial Engineering & Production Research (2018)

September 2018, Volume 29, Number 3
pp. 277- 291

DOI: 10.22068/ijiepr.29. 3.277 http://IJIEPR.iust.ac.ir/



Project Scheduling Problem with Resource Constraints and Interruption of Activities Using Bees Algorithm

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KEYWORDS
Planning;
Project scheduling;
Activities interruption,
Bees algorithm,
Resource constraint.

ABSTRACT
Project scheduling problem with resource constraints is a well-known problem in the field of project management. The applicability of this problem created a tendency for researchers towards it. In this study, project scheduling with resource constraints and the possibility of interruption of project activities has been considered, and renewable resource constraint has been also applied; in addition, a case study on construction projects has been also presented. Construction projects involve complex levels of work. Making wrong decisions in selecting methods and in allocating the necessary resources, such as manpower and equipment, can lead to the results such as increasing the predetermined cost and time. According to NP-Hard nature of the problem, it is very difficult or even impossible to obtain optimal solution using optimization software and traditional methods. In CPM project scheduling method, critical path is widely used in order to schedule the problem; however, in this method, the resource constraints are not considered. Project Scheduling seeks proper sequence to perform the project activities. This study has been conducted using Bees meta-heuristic algorithm, with the aim of optimizing the project completion time. Finally, the results obtained from three algorithms and GAMS software reflect that this algorithm outperforms the others, provides the best solution, and is able to reach the exact solution.

1. Introduction

In today's competitive environment, companies that produce their products through a project or a set of operations need to run numerous projects in their organizations. Many organizations and companies have put projects on the agenda such that their successful completion is only possible using project management techniques and procedures required for implementation. In the operation research, the project scheduling has attracted the most attention, hence its importance to various industries.

Project scheduling problem with limited resources was raised for the first time in 1963 [1]. The use of project management methods dates back to about fifty years ago; during this time, great effort was made on project management and on developing project scheduling models.

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Received 21 November 2017; revised 4 August 2018; accepted 6 October 2018

The purpose of the project scheduling is to determine the time of various activities during the implementation of the project that resulted in a decision-making process in which optimizing one or multi objectives is intended; in fact, it shows the proper sequence of activities, and the goals can include minimization of the project completion time, costs, and so on. The project scheduling includes constructing a project based on a plan that determines priorities and possible resources for each activity of a project. The different production operations include landing and takeoff of the airplane in the airport, the steps for conducting construction projects, and so on. The project-scheduling problem with resource constraints is the most general form of the scheduling problem; Job Shop Scheduling problems, the job shop flow, and other scheduling problems are subsets of it.

Project scheduling is a complex process that requires a lot of resources and activities that need optimization so as to attract increasing attention to a variety of applications in industry, production flow engineering, maintenance and construction in the past few decades. Initial solution method is focused primarily on heuristic rules. Minimum interruption (MSLK), the latest start time (LST), the earliest start time (EST), the shortest processing time (SPT), the latest finish time (LFT), most of substitutes (MTS), worst case disruption (WCD), and resource scheduling method (RSM) are among the methods that obtain higher-quality meta-heuristic solution (meta-heuristic), which have been widely adopted in recent years.

The RCPSP model is a very capable model; however, it cannot manage all circumstances in reality and practice. Because of the NP-hard nature of the mathematical model, Bees, Tabu search, and Genetic meta-heuristic algorithms have been used for real data; the GAMS software has been used to prove the feasibility of the model. The bees algorithm has been able to achieve exactly the optimal result from the GAMS software. Developing a good scheduling is essential to implement the project, and the main purpose of this paper is to minimize the time of the action.

2. Literature Review

According to the Project Management Institute (PMI), the project consists of a series of unique and temporary activities to fulfill a commitment and supply a specific product or service [2]. Projects are very pervasive in today's world, such that people and organizations are always involved in a variety of them [3]. The project includes activities related to each other by finishing the start of the priority relationship with a time lag from zero, requiring a set of renewable resources [4]. At first, the importance of project management was not recognized in industry and academic environment; therefore, tools such as CPM and technical evaluation and review of the project (PERT[2]) was of interest to clinicians and researchers. One of the challenges in the management of product development projects is to identify proper sequencing of many pairs and interconnected activities. Critical Path Method (CPM) is divided into two independent sections and is commonly used because of convenience and comprehensibility [5]. The project is a limited and specified activity that needs necessary resources and facilities to be completed at a specified time [6]. The project planning includes the construction of a priority and a feasible schedule where the process of identifying the start and end of the activities is under a particular purpose. Resources used for the activities of a project are classified based on their amount and nature. Because resources are usually limited, the project schedule constraints should be included in their descriptions [7]. Project scheduling is a complex process that includes a variety of activities that require resource optimization and scheduling methods that are commonly used in the operation. Projects may exist in any sector including the economy, manufacturing, healthcare, education, and government [8]. Resource constraints and project scheduling problem (RCPSP[3]) is one of the most well-known NP-hard problems where project activities must be scheduled to minimize the duration of the project [9]. Project scheduling problem with resource constraints is to plan project activities under resource constrain. RCPSP is in the field of operations research and management and is very common in a variety of fields such as engineering, medical research, and the RCPSP software [10]. Many project-scheduling problems can be formulated as RCPSP problem, such as job shop scheduling, store flow planning and scheduling, open shop scheduling, and project scheduling. For both purposes of research and university practical schedule, developing effective algorithms for solving RCPSP is very important [11]. It is

[2] Program Evaluation & Review Technique
[3] resource-constrained project scheduling problem

assumed in traditional methods such as PERT and CPM that resources are unlimited. In fact, these methods do not consider resource and costs constraints. Hence, it is possible that the obtained plan is not an executable plan. The project scheduling problem is related to the controlling, planning, time, cost and resources management of the activities of a project, and the project manager is required for optimal use of available resources. Because, in many cases, the implementation of these activities requires multiple resources, the resource constraints problem arises. Resource constraint can be considered for renewable and non-renewable resources. Each resource has a unique capability and skill [12]. Although a large number of practical applications are multi-skilled, it is in this case that human resources are also included [13]. In general, resources are classified into the renewable, nonrenewable, and dual-constraint resources whose amounts vary in each period; their amount is limited in any time period and may be different from one period to another. Renewable resources are those that can be renewed from one period to the next period; their only limitation is the amount used in a period; the renewable resources include machines and human resources available in each period [12]. In some cases, budget can be among these constraints so that the entire budget for the project is limited. The resources with dual constraints are the resources that not only are limited to be used in each period, but their amount is limited to the entire project [14], [15]. Each project consists of a number of activities in the form of specific works, operations, and tasks that must be done to finish the project. These activities can be cracked or broken and are formed as dependent and independent [16]. Each activity is usually described by its duration and set of resources, and these resources are used across activity [15]. If an activity can stop during running and continues in the future, the activity is named "Preemptive"; otherwise, this activity is "non-Preemptive" [17]. The problem is strongly NP-hard [18]. To solve different optimization problems, the different optimization techniques should always be used. Researchers have widely studied RCPSP and some of its expansions in the past decade [19]. The exact methods of heuristic and Meta-heuristic are detailed procedures with the ability to find the optimal solution [20]. The heuristic algorithm is composed of two main parts: 1. choosing the best answer; 2. Random generation. Choosing the best answer ensures convergence towards optimality. On the other hand, a random selection or random generation (feasible solution) prevents the trap of local optimal solutions and causes divergence in solutions. The right combination of these two sectors guarantees the achievement of the global optimal point [11]. A variety of projects scheduling problems studied so far [21],[22],[23] that considered timing with unavailable interval times for the resources. The aim of these studies is to minimize the duration of the project. In the project scheduling with resources constraint (RCPSP) problem, which is among the NP- Hard problems, it is proved that the use of accurate methods for large-sized problems can lead to an acceptable and reasonable solution [24]. In practice, the specific software is used for the scheduling process. This applications are based on a formal model that allows real project to be described with just one set of timing constraints and an objective function [25].

2-1. The difference between the present study and the other studies

Zheng & Wang (2015) investigated the project scheduling problem with the renewable resources constraint and monotonous and non-interruptible activities, aiming to minimize project makespan using the Multi-Agent Optimization Algorithm (MAOA). The project includes J activities, where each activity j , (j= 1, 2, …, j) is processed with dj time and without precedence. There is priority relationship between several activities. This means that activity j cannot start before finishing previous activities. In addition, the renewable resources are available for the project. Activity j needs r_{jk} units of K resources during the period. Dummy activities 0 and j + 1 represent the start and finish of the project. The results reflect that MAOA is a very competitive offer and is particularly suited to solve large-scale problems. The MAOA is also very simple for RCPAP project scheduling problem, and search operators should be studied further; as an optimization algorithm, the convergence of MAOA and parameter settings need to be further investigated. Afshar-Najafi & Majlesi (2014) investigated the project scheduling problem with renewable resources constraint and preventive activities, aiming to minimize project makespan using the Genetic Algorithm (GA). In their research model, an activity can be preventive after the consequence time. The number of each pre-emption is not limited to one activity. Setup time needs to start each activity after the prerequisite. Setup time is definitive and the schedule plan is independent. Setups are inseparable, i.e., activities are immediately finished after launching. Restart happened after precedence requires a lot of renewable resources with the activity plans that are processed. All of the parameters are integers. According to the results, GA algorithm is able to find a satisfactory solution in a CPU Time with the average percentage of deviation of makespan, and it is not useful for non-preventive $RSPSP_S$ in PSPLIB.

In the present study, the project scheduling was examined with renewable resources constraint and single-mode and non-interruptible activities, aiming to minimize project makespan, optimal utilization of resources, and algorithm evaluation and find the answers with less iteration using the bees algorithm. In the model presented in this study, each project consists of two starting and finishing dummy activities with activity time of 0 and needed resources of 0. The resources are considered renewable. The objective function is to minimize the total completion time of the project. Each activity has a specified time to complete. Each activity can start when the required resources are available. The crossover nature of the activities has been included in the mathematical model. The activity interruption results from the amount of resources available for the work in each day. All parameters are considered as definitive. The variables are binary. The results are compared with the best solutions obtained from 3 algorithms and GAMS software that have provided balanced performance; the Bees algorithm has exactly achieved the right solution. Then, the algorithm parameter adjustment was done, and the Taguchi method was used. The obtained results reflect the quality of the algorithm. This study introduces a single project problem, and the results indicate that the proposed algorithm can solve this problem on a larger and multi-project scale.

2-2. The research gap

According to the research literature and background, one of the previous research drawbacks was that the activities were not considered as crossover and did not implement the real data (case study). In this research, attempt is made to address this research gap.

3. Problem Statement

Project scheduling, considering resource constraints, is the project activities scheduling with respect to precedence relationship and resource constraints. RCPSP problem includes a project with J activities that is displayed as j = 1, ..., J; the time for completion of each activity j is displayed with $\mathbf{D_j}$. Each activity can be started only once, and activity can or cannot be Preemptive. Due to technical requirements, a set of precedence relationships exists between activities, such that, in this case, a set of relationships is displayed as $\mathbf{P_j}$, indicating that activity j cannot be started until all of its prerequisites and requirements are completed. Precedence relationships can be displayed using the Activity on Node (AON) networks where non-circularity of the network is displayed with this assumption. Each activity needs a certain amount of resources so that it can be carried out and run. The resources are considered renewable, which can be renewed from one period to the next period, and their usable amount in a period is their only constraint; the renewable resources include machines and human resources available in each period. The workers in a construction project can be considered as a renewable resource. If K is a renewable resource in the available project, the resources are displayed as $K = 1,...,k$. For each resource k in each period, there is access level that is constant all the times; this level of access to renewable resources is defined as R_k . Activity j needs $\mathbf{r_{jk}}$ unit of resource k in each period in which the activity is running. Two dummy activities of $J = J + 1$ and $J = 0$ that indicate the start and ending times of the project are also considered so that the time to complete of these activities is zero, and they need no resource. The purpose of this problem is to find a schedule that determines the start times for activities $\mathbf{j} = 0,\dots, \mathbf{j} + 1$ such that the schedule objective, namely minimizing the project completion time, will be realized.

Brucker et al. (1999) created a set of symbols for the classification of these problems. This symbol leads to the three main symbols created by Graham. About the project scheduling, symbol α is allocated to the resources and symbol β describes activities and can take more than one value and finally, symbol γ indicates the problem objective or objectives. RCPSP standard model is displayed as $\boldsymbol{ps}|\boldsymbol{prec}|\boldsymbol{C}_{\max}$ that represents the project scheduling problem with precedence relationships between activities and minimizing the completion time of the project, respectively. Although the model RCPSP stated above is a very capable model, it cannot cover all

$$Min \sum_{t=EFT}^{LFT} t.x_{nt} \quad (1)$$

$$\sum_{t=EFT_i}^{LFT_i} x_{it} = d_i \quad \forall i \quad (2)$$

$$\sum_{t=EFT_j}^{LFT_j} t\,x_{jt} \le \sum_{t=EFT_i}^{LFT_i} t\,x_{it} - d_i \quad \forall (i,j) \in A \quad (3)$$

$$\sum_{i_{k,t}=1}^{n} \sum_{t=\max\{t,EFT_i\}}^{\min\{t+d_i-1,LFT_i\}} r_{ik}\,x_{it} \le a_k \quad \forall t \in T, k \in K \quad (4)$$

$$x_{it} \in \{0,1\} \quad \forall i,t \quad (5)$$

situations in reality and practice; therefore, many researchers have developed many general models to the project schedule problem that often starts with a standard RCPSP as a starting point [25].
The following assumptions are considered for the problem:

• All parameters are predetermined and definitive.
• Each project contains two initial and final dummy activities with the activity time of 0 and needed resources of 0.
• Renewables resources are considered; meaning that there are a certain number of resources available per unit of time (day).

3-1. Mathematical model
3-1-1. Indices:

n : Total number of activities

K : Total number of resources

T : Total number of day(time horizons)

i , j : Index of Activities (1,…,n)

t : Index of day (1,…,T)

k : Index of resources (1,…,K)

3-1-2.Variables
X_{it} : If activity i is done on day t, 1 is otherwise 0

3-1-3. Parameters:
A : Answer vector

d_i : Duration of activity i

r_{ik} : Required resource k for activity i

a_k : Available resources k per day

LFT : The upper limit for completing the whole project

EFT : Earliest completion time of activity

• The first objective function represents the minimization of the total project completion time
• The first constraint represents that any activity is done according to its required time.
• The second constraint ensures that every activity can be started after ending its precedent activities.
• The third constraint ensures that any activity can be done when enough resources are available for doing that activity.
• The fourth constraint is the type of variables .The variables are binary.

The crossover nature of doing activities has been included in the mathematical model as an innovation. According to the third constraint, the activity disruption results from the amount of resources available for the work in each day. This means that if the resources needed by the i^{th} activity are less than or equal to the available resources among all resources, the resource is available for that activity. Thus, the t^{th} day will be added to the i^{th} activity. It means that it does not occur in succession. On the third day, there may be source and the activity is done; however, on the fourth day, work is not done. We continue this as long as the number of elements of d_t is equal t_i. If t_i is reached, the first constraint is applied.

4. Solution Methods
Due to the NP-hard nature of the problem (Messelis, 2014), obtaining an appropriate solution to this problem is very difficult and even impossible using conventional methods. Therefore, in this study, meta-heuristic methods are employed. Hartmann (1998) used a permutation-based Genetic Algorithm (GA) using regret-based sampling and LFT rule for the initialization [26]. Wu et al. (2011) proposed improved immune algorithm under chaotic conditions. Shou (2015) used particle swarm method in project scheduling with preventive resources constraint. [27], [20]. The result of this research is to reduce the project time. [28] examined project scheduling problem with resource constraints by the effective branch and price algorithm. [29] utilized the CPM/LOB Scheduling method for project time constraint. The GAMS software has been used in the present study to solve this model; in addition,

metaheuristic methods, such as Bee, genetic and Tabu search algorithms, are used whose results obtained from algorithms and GAMS software are compared with each other. Many complex multi-variable optimizations cannot directly be solved at a limited computational time in polynomial form. This leads to a search algorithm that finds near-optimal solutions at acceptable executive times. This algorithm is derived from the foraging behavior of bees, and it can be considered as a "smart simulation tool". Bees Group for the colony internal autonomy and distributed functions as well as an internal system is one of the best colonies for explaining these issues [30]. For this reason, Bees Algorithm is used in this study to solve the problem. Bees Algorithm is based on searching that was firstly developed in 2005. This algorithm is the simulation of foraging behavior of the honeybee groups. In the basic version of this algorithm, a kind of local search is conducted that can be combined with random search to be used in hybrid or functional optimization [31].

Bees Algorithm is an optimization algorithm that was inspired by the Bees food searching behavior to find the optimal solution. This algorithm starts with n scout bees that were randomly distributed in the search space. Then, fitness of any of bees is calculated based on the objective function and is ordered based on of excellence criterion. In the next stage, m top bees will be selected based on the objective function; then, e best sites will be selected among m sites. In fact, m-e sites are places to which new bees randomly move. At the end of each step, the best bee at each site will be selected and will enter the next generation; n-m bees will be generated randomly and will enter the next generation with the selected bees. This continues until satisfactory results are achieved, or it continues based on other conditions such as time, etc. [30], [31]. (Pham et al., 2006), (Pham et al., 2007). Pseudo-code for this algorithm is as follows:

1. Setting algorithm parameters (number of good, average and bad sites, and the number of neighbors of each site)
2. Generating random initial population and evaluating their merits
3. Determining the good, average, and bad site
4. Neighbor production for good sites
5. Random motion to bad sites
6. In case of lacking the stop condition, go to Step 2

5. Case Study

The solution set of all activities is considered as a single permutation and is randomly generated between 0 and 1 for initial population. The improved precedency and system simulation is observed. In this study, the single-point crossover and swap mutation are used whose activities are considered as crossover. To compare solution methods for this model, a main example is considered to examine the results of different methods together (Figure 1).

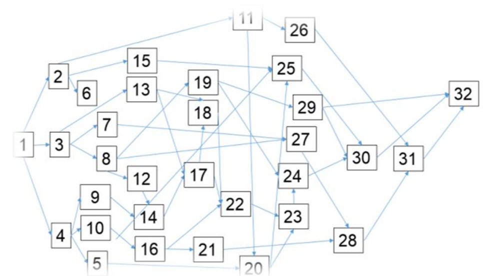

Fig. 1. Project Network

The fewer the number of iterations to achieve the optimal solution, the higher the convergence of the algorithm is. The optimal solution obtained from GAMS software is 37 for this model. This example was run 30 times with the equal number of function evaluation so that the equal terms would be set for all three algorithms. As can be seen, Bees algorithm has exactly reached the optimal solution (Figure 2) (Table 1).

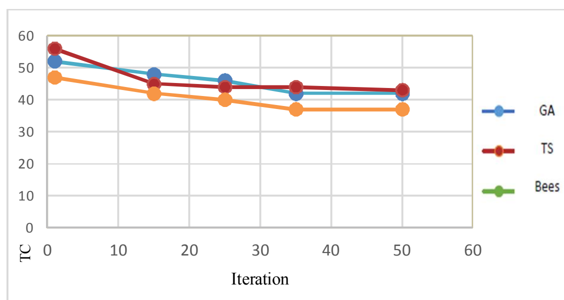

Fig. 2. The convergence diagram obtained from different algorithm

Tab. 1. Algorithms Performance

	Time	Objective function
GAMS	0.01	37
Bees	48	37
GA	45	42
TS	51	43

As it is clear from the results, the Bees algorithm has the best solution among the algorithms and can achieve the accurate solutions in this case. For better comparison of this algorithm's performance, ten different examples are produced whose problem dimensions are as follows (Table 2).

Tab. 2. Examples

Example	Number of activities	Number of resources
1	12	2
2	24	2
3	57	4
4	61	3
5	72	7
6	86	5
7	109	6
8	171	7
9	234	8
10	320	6

The obtained results are as follows (Table 3):

Tab. 3. Results

	Bees		GA		TS		GAMS	
NO	Obj	Time	Obj	Time	Obj	Time	Obj	Time
1	29	49	57	49	87	50	29	0.001
2	72	105	110	105	111	119	72	45623
3	139	182	260	215	148	295	-	-
4	153	400	300	524	373	461	-	-
5	205	612	734	730	812	1073	-	-
6	324	1110	1403	963	1439	1330	-	-
7	796	2470	2906	2218	2973	1588	-	-
8	1032	5233	6106	4811	4474	1753	-	-
9	1657	7591	11949	10419	5493	2948	-	-
10	3367	13405	14423	16464	12922	5152	-	-

5-1. The objective function

The objective function in this model represents the completion time of the project. As is clear from the results, Bees algorithm has achieved the best results among the algorithms.

5-2. Solution time

As is clear from the algorithms performance comparison table, the algorithms have shown moderate performance in terms of time.

5-3. Parameter adjustment

Statistics is used to process initial data in order to achieve optimal planning and scientific decision-making, and its applications is in the field of statistical quality control, design of experiments, data mining, and forecasting. Design of Experiments is a powerful statistical technique to improve quality and reduce costs in designing process or product. Most of the methods developed so far by various researchers to design experiments and analyze data in quality engineering are categorized under two main approaches of quality engineering and experiments classic design. There are many similarities between the two approaches including the applicability of the similar experiment designs. A basic difference between these two approaches is that in the classic design of experiments, the main purpose is to recognize the changes in averages and its adjustment, while the purpose of quality engineering is primarily to reduce scattering and, second, to adjust the average. In Taguchi method, factors are divided into two main categories: controllable and noise factors. Noise factors are those factors over which we have no control. Knowing the fact that the elimination of noise is not possible or affordable, Taguchi method seeks to minimize the impact of noise and determine the best level for the controllable factors. In addition to determine the best level of each factor, the Taguchi method seeks to determine the importance of each factor in terms of their main impact on the response variable. Taguchi method is a powerful experiment design that converts the response variable values into the signal-to-noise ratio (S / N). Generally, the term 'signal' represents the desired value (average response variable), and noise represents the amount of undesirable value (standard deviation). Thus, the rate of S / N refers to the amount of dispersion in the response variable. The objective is to minimize the rate of S / N. Taguchi converts the objective functions into three groups:

1. Type of whatever - smaller - better

2. Type of whatever - bigger - better

3. The best type = value – nominal, (Table 4)

Tab. 4. Parameters initial design

Parameters	Level 3	Level 2	Level 1
Pg	0.8	0.75	0.7
Pn	0.19	0.15	0.1
Pop size	150	75	25
Maxiter	700	300	100

Tab. 5. Objective function obtained from Bees algorithm

	Mean Fitness	454.94	22.96	5.71	23.87	126.33	21.76	124.58	54.00	12.41
		Sen1	Sen2	Sen3	Sen4	Sen5	Sen6	Sen7	Sen8	Sen9
data 1	run 1	50.63	0.60	0.22	1.52	8.10	1.85	1.69	4.35	0.72
	run 2	47.36	2.03	0.45	2.14	9.44	1.49	6.94	2.19	1.40
	run 3	45.29	1.51	0.45	1.70	1.98	0.71	12.02	2.26	0.81
	run 4	19.05	2.36	0.57	1.17	13.89	1.28	11.66	1.84	0.32
	run 5	26.80	1.13	0.46	2.31	7.18	1.44	2.94	4.22	1.41
data 2	run 1	62.09	6.35	2.14	10.49	8.11	1.99	50.00	7.48	2.73
	run 2	225.72	2.39	2.37	7.59	64.93	3.62	30.01	28.36	3.67
	run 3	178.73	4.26	0.32	6.72	29.11	8.97	60.73	23.90	2.39
	run 4	232.17	6.45	2.57	3.96	20.76	11.92	60.76	4.35	4.15
	run 5	221.82	5.48	0.28	4.29	9.59	4.02	59.65	18.95	5.80
data 3	run 1	468.97	17.01	6.78	30.54	193.86	21.84	93.57	8.42	9.18
	run 2	174.12	11.54	5.73	15.11	37.10	15.45	137.07	40.89	3.36
	run 3	86.13	18.59	3.24	17.86	81.76	25.91	87.28	20.31	4.21
	run 4	281.97	24.13	5.93	28.91	193.45	29.36	27.39	61.94	2.47

	run 5	484.28	19.87	5.88	15.56	177.94	18.80	18.96	37.30	11.64
data 4	run 1	775.44	36.69	6.13	39.87	78.38	23.95	250.08	25.32	5.46
	run 2	883.08	41.47	1.47	21.83	103.45	43.77	31.22	65.99	12.47
	run 3	1088.61	28.76	7.48	38.61	246.11	8.65	225.51	129.56	8.06
	run 4	284.78	18.19	6.44	16.01	93.10	32.38	236.66	54.52	6.63
	run 5	944.03	10.67	6.50	19.66	173.43	19.88	206.67	53.09	19.96
data 5	run 1	642.76	56.61	12.92	49.94	167.52	38.22	97.59	91.81	26.30
	run 2	309.89	44.52	12.07	60.59	129.69	7.06	352.87	65.41	33.19
	run 3	992.57	7.55	6.53	44.18	252.99	56.99	198.45	41.60	14.69
	run 4	1306.35	42.38	14.04	9.93	266.62	31.50	212.95	21.49	25.75
	run 5	454.56	32.88	11.24	61.73	299.40	14.13	38.07	154.04	33.33
data 6	run 1	1054.27	61.39	6.70	44.69	125.00	38.26	300.26	72.68	29.45
	run 2	365.14	62.93	11.82	8.62	413.47	58.37	92.91	132.12	28.19
	run 3	356.78	53.44	6.55	44.13	188.09	62.82	172.92	101.42	17.16
	run 4	495.52	54.67	10.24	44.41	199.82	27.79	341.80	187.41	30.20
	run 5	1089.40	12.99	13.84	62.06	195.64	40.44	318.65	156.75	27.11

Tab. 6. The problem scenario design

Scenario	Pg	Pn	Pop size	Maxiter
Scenario 1	1	1	1	1
Scenario 2	1	2	3	2
Scenario 3	1	3	2	3
Scenario 4	2	1	3	3
Scenario 5	2	2	2	1
Scenario 6	2	3	1	2
Scenario 8	3	2	1	3
Scenario 9	3	3	3	1

Tab. 7. Average of scenarios

Scenario	Level 1	Level 2	Level 3
Pg	161/2062245	57/32106607	63/66073404
Pn	201/1307475	67/76341527	13/29386186
Pop size	176/9014702	85/53957321	19/74698123
Maxiter	197/8942006	56/43333972	27/86048435

According to the Taguchi method, there are 9 different scenarios instead of $3^4 = 81$, so that, in each scenario, the parameters' description is shown the table above. In fact, the Taguchi method states that 9 modes should be reviewed instead of 81 modes. In the following, 9 scenarios with 6 examples and 5 iterations are made for each combination. The tables related to the obtained objective function, the signal/noise ratio, and RPD are provided in tables below. As can be seen, 6 examples were written for 9 scenarios such that each of them has been solved 5 times, and the values obtained from solving are the weighted average of the objective function. The results, presented in Table 7, are the average scenarios in Table 5 for each level that the excellent percentage, average percentage, total population and number of iteration of these results are shown in Figure 3. In each run, the obtained objective function value should be converted to the signal-to-noise ratio according to Taguchi method that is considered as the response variable, and the analysis should be done according to the changes (Table 5), (Table 6), (Table 7).

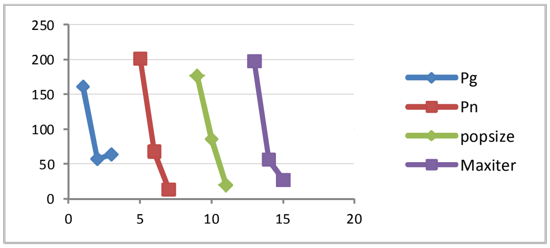

Fig. 3. The objective function

Since the goal is maximization, S/N ratio is considered as a proportion variable in the Taguchi method based on which the objective function will turn to this ratio in each run so that the decision can be made according to that which is calculated from the following equation:

$$S/_{N_l} = -10\log\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right)$$

Tab. 8. Signal to Noise results obtained by the Bees algorithm

	Mean S/N	-55.45	-29.72	-17.16	-29.84	-44.30	-29.04	-44.43	-37.49	-24.48
		Sen1	Sen2	Sen3	Sen4	Sen5	Sen6	Sen7	Sen8	Sen9
	run 1	2563.09	0.36	0.05	2.31	65.68	3.40	2.87	18.92	0.52
	run 2	2242.77	4.12	0.20	4.57	89.09	2.21	48.12	4.81	1.95
data 1	run 3	2051.57	2.27	0.21	2.89	3.91	0.50	144.40	5.10	0.66
	run 4	362.89	5.59	0.33	1.37	192.98	1.64	135.94	3.37	0.10
	run 5	718.04	1.28	0.21	5.32	51.50	2.08	8.67	17.79	1.99
	run 1	3855.42	40.38	4.57	110.01	65.83	3.97	2499.62	55.88	7.47
	run 2	50950.34	5.69	5.60	57.63	4216.16	13.13	900.73	804.48	13.50
data 2	run 3	31946.16	18.15	0.10	45.15	847.27	80.41	3687.93	570.99	5.70
	run 4	53904.36	41.66	6.58	15.67	430.78	142.09	3692.05	18.96	17.21
	run 5	49206.23	30.04	0.08	18.42	91.88	16.14	3557.65	358.92	33.68
	run 1	219934.23	289.30	45.95	932.96	37580.68	476.92	8755.76	70.83	84.35
	run 2	30317.42	133.14	32.86	228.17	1376.60	238.60	18789.54	1672.22	11.32
data 3	run 3	7418.84	345.67	10.51	318.91	6684.52	671.53	7617.17	412.49	17.77
	run 4	79507.95	582.44	35.21	835.67	37421.31	861.79	750.05	3836.40	6.09
	run 5	234525.81	394.96	34.56	242.22	31661.77	353.40	359.37	1391.42	135.50
	run 1	601308.17	1346.28	37.63	1589.50	6143.23	573.45	62540.74	640.91	29.84
	run 2	779832.68	1720.17	2.16	476.64	10701.56	1916.00	974.91	4354.12	155.59
data 4	run 3	1185074.95	827.01	55.94	1490.84	60569.57	74.84	50855.82	16786.74	65.02
	run 4	81102.22	330.96	41.48	256.33	8668.49	1048.60	56009.70	2972.47	43.98
	run 5	891200.76	113.93	42.20	386.47	30079.40	395.13	42713.28	2818.78	398.22
	run 1	413134.96	3204.38	166.90	2494.50	28063.24	1460.82	9523.58	8428.73	691.66
	run 2	96033.14	1981.76	145.70	3671.09	16819.38	49.86	124514.38	4278.07	1101.57
data 5	run 3	985195.35	56.97	42.65	1952.03	64005.62	3247.41	39380.49	1730.51	215.85
	run 4	1706550.41	1795.72	197.20	98.66	71085.80	992.21	45349.77	461.67	663.17
	run 5	206621.90	1081.30	126.24	3810.32	89643.29	199.80	1448.97	23728.40	1110.83
	run 1	1111490.28	3768.39	44.86	1997.45	15624.45	1463.83	90158.68	5281.68	867.16
	run 2	133329.27	3960.58	139.60	74.25	170957.15	3407.02	8632.44	17455.50	794.79
data 6	run 3	127295.44	2855.90	42.91	1947.59	35378.22	3945.74	29902.46	10286.15	294.44
	run 4	245538.20	2988.59	104.89	1972.26	39927.73	772.42	116828.01	35123.58	911.96
	run 5	1186788.84	168.75	191.56	3851.99	38275.59	1635.36	101540.58	24570.13	735.17

The results of running the algorithm are represented in the tables that indicate the performance quality of the algorithm. Four parameters are available in this diagram where three levels are set for each parameter. Based on the signal-to-noise diagram, the level with the higher value will be selected. In Figure 4, the third level is the highest level in three parameters of 2, 3, and 4. Therefore, Level 3 is selected for these three parameters. However, in parameter 1, because the levels are almost balanced and it is not possible to make decision properly, the tolerance of the algorithm performance will be calculated.

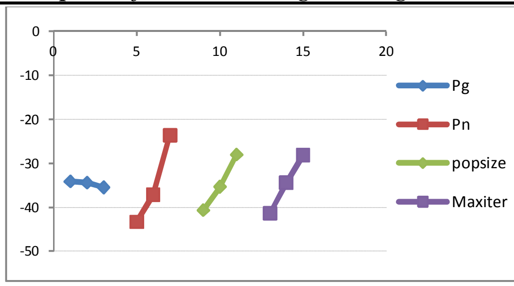

Fig. 4. Signal and noise diagram

(Table 8) shows how to calculate the amount of RPD. M_i is the value of the objective function that is obtained for each run of the algorithm. M_{min} is the lowest value of the objective function which is calculated for each sample problem by solving all three algorithms.

Relative percentage deviation (RPD) = $\frac{M_i - M_{min}}{M_{min}}$

Tab. 9. The obtained RPD Results for Bees algorithm

	Mean RPD	454.94	22.96	5.71	23.87	126.33	21.76	124.58	54.00	12.41
		Sen1	Sen2	Sen3	Sen4	Sen5	Sen6	Sen7	Sen8	Sen9
	run 1	50.63	0.60	0.22	1.52	8.10	1.85	1.69	4.35	0.72
	run 2	47.36	2.03	0.45	2.14	9.44	1.49	6.94	2.19	1.40
data 1	run 3	45.29	1.51	0.45	1.70	1.98	0.71	12.02	2.26	0.81
	run 4	19.05	2.36	0.57	1.17	13.89	1.28	11.66	1.84	0.32
	run 5	26.80	1.13	0.46	2.31	7.18	1.44	2.94	4.22	1.41
	run 1	62.09	6.35	2.14	10.49	8.11	1.99	50.00	7.48	2.73
	run 2	225.72	2.39	2.37	7.59	64.93	3.62	30.01	28.36	3.67
data 2	run 3	178.73	4.26	0.32	6.72	29.11	8.97	60.73	23.90	2.39
	run 4	232.17	6.45	2.57	3.96	20.76	11.92	60.76	4.35	4.15
	run 5	221.82	5.48	0.28	4.29	9.59	4.02	59.65	18.95	5.80
	run 1	468.97	17.01	6.78	30.54	193.86	21.84	93.57	8.42	9.18
	run 2	174.12	11.54	5.73	15.11	37.10	15.45	137.07	40.89	3.36
data 3	run 3	86.13	18.59	3.24	17.86	81.76	25.91	87.28	20.31	4.21
	run 4	281.97	24.13	5.93	28.91	193.45	29.36	27.39	61.94	2.47
	run 5	484.28	19.87	5.88	15.56	177.94	18.80	18.96	37.30	11.64
	run 1	775.44	36.69	6.13	39.87	78.38	23.95	250.08	25.32	5.46
	run 2	883.08	41.47	1.47	21.83	103.45	43.77	31.22	65.99	12.47
data 4	run 3	1088.61	28.76	7.48	38.61	246.11	8.65	225.51	129.56	8.06
	run 4	284.78	18.19	6.44	16.01	93.10	32.38	236.66	54.52	6.63
	run 5	944.03	10.67	6.50	19.66	173.43	19.88	206.67	53.09	19.96
	run 1	642.76	56.61	12.92	49.94	167.52	38.22	97.59	91.81	26.30
	run 2	309.89	44.52	12.07	60.59	129.69	7.06	352.87	65.41	33.19
data 5	run 3	992.57	7.55	6.53	44.18	252.99	56.99	198.45	41.60	14.69
	run 4	1306.35	42.38	14.04	9.93	266.62	31.50	212.95	21.49	25.75
	run 5	454.56	32.88	11.24	61.73	299.40	14.13	38.07	154.04	33.33
	run 1	1054.27	61.39	6.70	44.69	125.00	38.26	300.26	72.68	29.45

	run 2	365.14	62.93	11.82	8.62	413.47	58.37	92.91	132.12	28.19
data 6	run 3	356.78	53.44	6.55	44.13	188.09	62.82	172.92	101.42	17.16
	run 4	495.52	54.67	10.24	44.41	199.82	27.79	341.80	187.41	30.20
	run 5	1089.40	12.99	13.84	62.06	195.64	40.44	318.65	156.75	27.11

The lowest level will be selected, as shown in Figure 5. Level 2 is the lowest level of parameter 1 in this diagram. Levels 3, 3 and 3 were the selected levels for the next three parameters. Therefore, the levels selected for the first, second, third, and fourth parameters are 2, 3, 3, and 3 respectively.

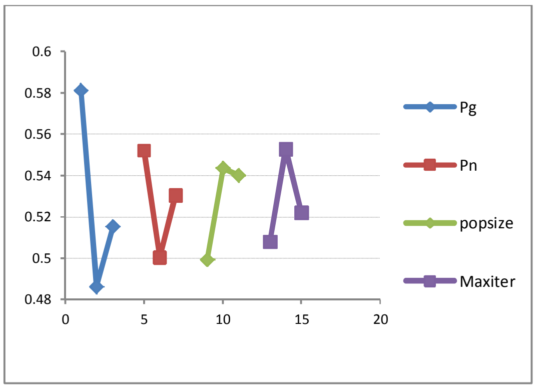

Fig. 5. The algorithm performance tolerance diagram (RPD)

Thus, according to the obtained values, the best value for the parameters according to the levels specified in (Table 4) are shown in (Table 10) and (Table 11).

Tab. 10. Parameters values

Pg	0.75
Pn	0.19
Pop size	150
Maxiter	700

Tab. 11. Displaying the values in parameters initial design

parameters	Level 3	Level 2	Level 1
Pg	0.8	0.75	0.7
Pn	0.19	0.15	0.1
Pop size	150	75	25
Maxiter	700	300	100

6. Conclusion

The solution set for all activities is considered as a single permutation and is randomly generated between 0 and 1 for the initial population. Improved prerequisite and system simulation were considered. In this study, single-point crossover and swap mutation were used and activities were considered as crossover. A main example was considered in order to compare the solving methods for this model so that we could examine the results of methods together. The introduced algorithm was coded by MATLAB software and was implemented for a case study in the field of civil projects; the best results obtained from the model using 3 algorithms and GAMS software were used, and the solution methods were compared in order to test the algorithm performance. The optimal solution obtained from the GAMS software was 37 for this model that was obtained by 30 runs with the equal number of the function evaluation so that there would be equal terms for all three algorithms; the Bees algorithm reached the optimal solution. For better comparison of the algorithm's performance, ten different examples were produced. The objective function in this model represents the completion time of the project. The results indicated that the Bees algorithm earned the best solution among the other algorithms; the algorithms also provided balanced performance in terms of the time to solution; then, the algorithm parameter setting was done and the Taguchi method was used. The results obtained from the algorithm reflect the performance quality of the algorithm. The present research introduced the environment of a single-project problem, and the results indicated that the proposed algorithm could solve this problem on a larger and multi-project scale.

Suggestions for future works

Some suggestions are presented in this section to conduct studies in line with current research including consideration of the multimode activities, applying in multi-project environment, incorporating new meta-heuristic algorithms which have not been studied in this problem so far, developing new metaheuristic algorithms which have not been studied in this problem, fuzzifying the input parameters, and studying the model in probabilistic mode, which can be examined by researchers interested in this field.

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