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A multi-objective mathematical model for planning, scheduling and increasing projects productivity

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Abstract We aimed to develop a mathematical method for planning, scheduling and increasing the productivity of projects with multiple goals, including reducing project time, resources, and negative cash flows, increasing floatiness of activities, and responding to the project's needs by considering various stakeholders and objectives. As such problems are NP-hard, particle swarm optimization was used to solve the multi-objective mathematical model. Then, the algorithm function was evaluated by changing the value of the parameters. We are looking for the use of multi-objective models for planning projects, which allow for planning each activity in different modes and functions using multiple objectives, enables project managers to implement their projects by considering various priorities. Based on previous studies on project schedules, it seems that most of them focus on reducing time and cost; nevertheless, this study intended to investigate issues like various operational modes of each activity, optimal and in-time allocation of resources, and to increase floatiness of activities.

Keyword: Project Scheduling, Multi-Objective Modeling, Particle Swarm Algorithm, Minimizing Time of Resources and Cash Flows, Maximizing Activity Floatiness.

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1 Introduction

Regarding the extent and complexity of projects, planning is the prerequisite of achieving pre-defined goals. One of the essential parts of project management is the art of evaluating, planning, and monitoring. Project management intends to set a schedule for activities and technical aspects to reach the best outcome at the lowest cost in the shortest time. Therefore, scheduling is one of the essential principles for construction projects' success [1]. All project scheduling methods are looking to optimize time and cost. Multi-objective planning methods can be valuable to achieve this goal, which is used to optimize various outcomes.

In general, projects are designed to meet a set of needs, and project managers intend to manage the project based on its path to achieve predetermined goals. Often, most projects contain different objective functions for several reasons, one of which is the high number of

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stakeholders. The project planning and control system is a set of questionnaires, information receiving forms, pre-made techniques or programs, methods and resources that are related and related to each other. The purpose of the project planning and control system is to guide the project according to the defined schedule and budget and provide the final goals of the project. In one sentence, it can be said that project planning and control is developed to help project managers to optimize time and cost in projects [2].

The classical problem (RCPSP) involves the scheduling of a single-state project in order to minimize the project completion time with regard to prerequisite relationships and resource constraints. In this type of problem, the activities have a type of execution method and the duration of the activity and its need for a set of fixed resources are assumed. As the situation became more complicated, many managers faced the challenge that each of the project activities may be done in more than one way, and each of these ways has a different time period and cost. In this way, project scheduling with limited resources including activities under multiple implementation methods (MRCPSP) was created. [3, 4]. Various methods for solving RCPSP problems including exact mathematical methods, branch and bound methods, heuristic methods and meta-heuristic methods were proposed over time. From the computational point of view, project scheduling models with limited resources are considered complex (NP-hard), so that the calculation time to find the optimal solution of the problem increases with the increase of the number of variables and restrictions.

Primary objectives include optimizing project duration, cost, quality, net present value, safety, and flexibility in the scheduling [5]. Solving project planning problems with resource constraints intending to minimize activities time should be according to priorities. As such problems are NP-hard, and regarding the high number of activities that should be performed in a reasonable time, the time to perform such activities is long and requires innovative and meta- heuristic methods. Many different sciences and engineering can be considered in the Jirga of contract optimization problems. Optimization methods can generally be divided into two categories: exact methods and innovative and meta-innovative methods. Exact methods such as dynamic programming, linear and numerical programming Exact and Lagrange-based methods are considered to find the final solutions, however, these exact methods have a very high and impressive execution time and can only be used for small or medium-sized problems in the real world and to solve problems. It can be said that the use of meta-heuristic algorithms is the only efficient solution. However, the limitation of these methods is that they may never find the exact optimum, but instead they find near-optimal solutions in a reasonable time [6].

Therefore, the current study aimed to provide a model to respond to the project needs. The model solution is based on the meta-innovative Particle Swarm Optimization (PSO) method for construction project planning and optimization of the project objectives [7].

2 Literature review

One of the critical aspects of project management is the Resource-constrained Project Scheduling Problem (RCPSP) that has received the attention of researchers since the 1950s. The methods mentioned above, such as the Critical Path Method (CPM), Program Evaluation and Review Technique (PERT), and Graphical Evaluation and Review Technique (GERT), are based on the assumption of permanent sufficiency of resources. Hence, the impact of resources is not considered, which is not realistic for all cases. In addition, this assumption means that the initiation of activities cannot be planned based on the nearest time.

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RCPSP is a practical project scheduling solution attracting the attention of several researchers due to its computational complexity (NP-hard). RCPSP intends to improve the decision-making process to optimize objectives that significantly contribute to managerial projects and achieve high productivity (i.e., time, cost, and resources). Scarcity of resources indicates the necessity of considering a set of constraints in project planning, in which activity duration and resources are known as requirements. While activities are connected based on the prerequisite restrictions, the main goal of each solution is to minimize the time while respecting priorities and constraints. In other words, each project is unique because activities cannot be performed in predetermined points; unless a project is quite similar to another one. As these problems are NP-hard, it is challenging to find an optimal solution with logical time due to their complexity and combined features [8]. Most project management programs developed for different target functions contain priorities and feasible programs based on resources [3]. However, the shortage of resources and risk of accessible information is increasingly felt.

RCPSPs with a single function are based on performing each activity with an executive method, and the duration and time of the activities, as well as their requirements, are assumed to be fixed. However, for the Multi-state RCPSP Problem (MRCPSP), each activity can be performed using one of the executive methods, which should be done by that method. Each method requires different durations, requirements, and resources.

Table 1 Different methods to solve RCPSP problems

Row	Approach	Method	Benefits	Weakness
1	Precise	linear programming Non-linear programming Integer planning Implicit enumeration branch and bound	Providing accurate optimal solutions for small projects	Only suitable for small projects The high number of assumptions
2	Innovative methods	One-way methods Multi-way methods	The provided solution may not be accurate The size of the project is not important	It requires experience A pilot sample is needed to ensure the quality.
3	Meta-innovative methods	Genetic algorithm Particle swarm algorithm Ant colony algorithm	Addressing the weaknesses of the previous two methods	Coding is complicated due to the variety of methods

RCPSP aims to minimize the length of the project by considering resource constraints and prioritizing activities. The multi-state project scheduling problem is faced with the scarcity of regular resources, in which the duration of each activity is a function of the level and type of necessary resources.

Recently, increased attention has been paid to RCPSP due to its scientific importance and the computational challenges of other models. Unlike previous efforts focused on modifying a base model, currently, most research aims to develop a better solution method with more diverse goals. RCPSP and M-RCPSP problems contain various models to provide an optimal solution. For instance, some researchers focused only on optimizing project time and did not include other objectives such as cost and quality. Although some researchers only considered the project duration in their models, others also considered the cost variable. In other words, they examined the cost-time balance in their models. Some researchers have also included the quality of activities, in addition to the length of the project and its costs, and developed their model based on the optimization of three objectives of time, cost, and quality. Generally speaking, the balance of time, cost, and quality are investigated. An increasing need is felt over time to develop more comprehensive programs to meet the needs of various stakeholders. Therefore, the current study aimed to investigate project scheduling while paying attention to other issues related to this problem.

3 Methods

The project scheduling problem has attracted the attention of many researchers in recent years, which can be attributed to the challenging features of these problems in modeling the solving methods and algorithms. While it seems that previous studies reported different results, and Hartmann et al. [3] reported similar findings regarding the modeling of the problem, and the difference is about the categorization and mathematical equations. The first multi-objective planning was presented in 1981. However, a few studies followed this approach, despite extensive research on project scheduling [9].

Using multiple objectives in solving problems allows managers and analysts to consider various dimensions of a project. Managers always prioritize minimizing the project time and resources and reducing cash flows. Innovative and meta-innovative methods should be used for multi-objective planning in project scheduling, as they are categorized as NP-hard. According to previous studies, PSO is effective regarding its speed and accuracy. Previous studies indicated the need for further investigation of multi-objective scheduling in construction projects. Based on what was mentioned before, this study develops a multi-objective mathematical model for scheduling construction projects to optimize the various objectives and requirements of such projects. Such a model requires considering all goals. Hence, the following objectives were defined:

- Time minimization:

1: Minimize T=S_n

Minimization and homogenization of financial flows:

2: Minimize C=$MAX\{CF_t\}$

Minimizing resource levels (leveling resources):

3: Minimize

$$RLI=\log\left(\sum_{k\epsilon K}\left(\frac{C_k}{T_{min}}\right) * \sum_{t=0}^{T}\sum_{i\epsilon I}(r_{ikt})^2 + \sum_{k\epsilon K} u_k * \sum_{t=0}^{T}\sum_{i\epsilon I}(r_{ikt})^2\right)$$

Minimization of negative cash flows:

4: Minimize NCF=$abs\left(\sum_{t=0}^{T}\min\{0. CF_t\}\right)$

Maximizing the schedule sum of total floats

5: Maximum SS=$\sum_{i\epsilon I} TF_i$

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Table 2 Model parameters

Duration	T
Total cost	C
Level of resources	RLI
The total sum of negative cash flows	NCF
Sustainability of the program	SS
Project activities (1 to n)	I
Total number of prerequisite activities	H
Sum of renewable resource	K
Resource	k
Total resources	R
Duration of activity i	d_i
Number of activities from t to t-1	S_t
Number of resources required from resource k to perform activity m from i set	r_{ikm}
Resource costs including procurement, installation, equipping, dismantling, and maintenance	C_k
The procurement cost of resource k	c_k
Dismantling cost of resource k	dc_k
Costs related to installing and equipping resource k	mc_k
Need for resource k to perform activity i	r_{ik}
Amount of resource k needed to perform activity i at time t	r_{ikt}
Rate or ratio of resource cost k for activity i	u_k
Cash flow at t	CF_t
Amount of resources available from resource k	m_{ak}
Fixed costs of activity i	Fc_i
Floatiness of activity i	TF_i

It is worth noting that for renewable resources, RCPSP is a one-time cost, i.e., its amount would not increase by repetition, which is valid for most equipment used for construction projects, including the cost of procurement, equipping, installation, dismantling, and maintenance. However, the cost of rental equipment or human resources differs in terms of person/hour. For instance, administrative affairs only require human resources, or some activities only need equipment. Usually, the more the extent of the program, the higher the value of RLI. Therefore, equation 3 is a logarithm function that is limited to correctly measuring the search space.

Model limitations:

Two types of limitations can be considered.

Type one, the main limitations:

- The first activity starts on day one.

  1: $S_1 = 1$
- Prerequisite relations that define all logical relations between activities. The relations are start-to-start.

  2: $S_i + L_{i.j} \le S_j \quad \forall \quad i.j\epsilon I$
- Cross-sectional sequences that define logical nodes at different levels of an activity, which can be used for planning at different stages.

  3: $S_j + 1 \le S_i \quad \forall\, i.j\epsilon I$

Voluntary constraints that mainly reflect the specific needs of the project, as follows:

4: $S_i \le \overline{T}$

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$$5: \sum\nolimits_{i\epsilon A} FC_i + \sum\nolimits_{k\epsilon K} ((mc_k + dc_k + c_k) * MAX\left\{\sum\nolimits_{t=0}^{T} r_{kt}\right\}) \le \overline{C}$$

$$6: CF_t \le | \overline{NCF} | \quad \forall t = 1.2 \dots .T$$

$$7: \begin{cases} a_k \ is\ a\ set : \sum\nolimits_{j\epsilon I_t} r_{ikt} \le a_{kt} \\ \quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad\quad \forall a_k \epsilon R_A \ \ t = 1.2 \dots .T \\ otherwise: \sum\nolimits_{j\epsilon I_t} r_{ik} \le a_k \end{cases}$$

$$8: \sum\nolimits_{i\epsilon A} (d_i * r_{ik}) \le a_k \quad \forall a_k \epsilon R_T$$

$$9: \begin{cases} CF_{t=S_i} = \sum_{k=1}^{K} mc_k * r_{ik} + \sum_{k=1}^{K} u_k * r_{ik} + \dfrac{FC_{im}}{F_i - S_i} & \forall\ i\epsilon I\ \ and\ \ m\epsilon M \\ CF_{t=F_i} = \sum_{k=1}^{K} dc_k * r_{ik} + \sum_{k=1}^{K} u_k * r_{ik} + \dfrac{FC_{im}}{F_i - S_i} & \forall\ i\epsilon I\ and\ \ m\epsilon M \\ CF_{t>S_i\ \&\ t<F_i} = \sum_{k=1}^{K} u_k * r_{ik} + \dfrac{FC_{im}}{F_i - S_i} & \forall\ i\epsilon I\ and\ \ m\epsilon M \end{cases}$$

$$C_k = mc_k + dc_k + c_k$$

Table 3 Model parameters

Target time (defined time)	$\overline{T}$
Target budget	$\overline{C}$
Maximum financial liquidity or maximum negative cash flows	$\overline{NCF}$
Set of time limitations	ATC
The available amount of resources at each time indicates the availability of resources at each time	R_A
Initiation time	DD
Time initiating activity i	S_i
Delay or interval between activities i and j	$L_{i.j}$
Time of activity i in operational mode m	d_{im}
The selected operational mode of activity i	m_i
Operational modes of activity i	M_i
A set of prerequisite or logical relations, including latency or time lag between activities	L
Total renewable resources that a project can use	R_T
The maximum amount of resource k	a_k
The maximum amount of resource k at time t	a_{kt}
Amount of resource k to perform activity i at time t	r_{ikt}
Amount of resource k to perform activity i	r_{ik}

Particle Swarm Optimization method

The reasons for choosing this method are described in the following.

Kennedy and Eberhart [10] introduced the PSO, which is among swarm intelligence techniques. The PSO relies on the principle that every particle adjusts its location according to the best place ever located in the search space. A flock of birds randomly looks for a target.

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There is only one target that any bird does not consider. Following birds with the lowest distance to the target can be one of the best strategies. Each solution, named a particle, is equal to a bird in a swarm algorithm. Each particle contains a level of merits, which is calculated by a merit function. The closer the distance to the target, the higher the level of merits. In addition, each particle has a velocity that controls its movement. Each particle follows the optimal particles in the search space; that is; initially, there is a group of particles created randomly to identify the optimal solution by updating generations. Each particle is updated using the two best-obtained values. The first value is the best-achieved status of the particle. The second value is the best location the flock has had.

As mentioned earlier, one of the best advantages of PSO is simplicity. The original PSO, introduced by Kennedy and Eberhart [11], updates the velocity and position of each particle in each cycle.

$$V_{ij}^{t} = wV_{ij}^{t-1} + r_1 c_1 \left(L_{ij}^{t-1} - X_{ij}^{t-1}\right) + r_2 c_2 \left(G_{j}^{t-1} - X_{ij}^{t-1}\right)$$
$$X_{ij}^{t} = X_{ij}^{t-1} + V_{ij}^{t}$$

Where Vi is the velocity of particle i ($i \epsilon m$); V_{ij}^{t} and V_{ij}^{t-1} are the velocities of dimension j in repetition t and t-1. In addition, r1 and r2 are two random numbers ranging from zero to one. Also, c1 and c2 are two learning coefficients that indicate the impact of the best solutions, either a single particle or the flock, on new velocity values. X_{ij}^{t} and X_{ij}^{t-1} indicate the position of particle i in dimension j in repetitions t and t-1. L_{ij}^{t-1} indicates the position of particle i on dimension j in the best solution up to repetition t-1. G_{j}^{t-1}s is the position of dimension j on the best position vector up to repetition t-1. Besides, c1, a positive constant, is the self-recognition component coefficient, which is based on the best position of each particle. The higher the value of this coefficient, the closer the answer to the individual answer.

4 Findings

Inputs

This study examined and analyzed a proposed model on the presented problem using the PSO algorithm. Data were evaluated using various parameters, which directly impacted the results. The input information included a schedule for constructing a stadium affiliated with Iran's Development and Maintenance of Sports Facilities. This project contained 22 activities (Table 4).

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Table 4 Data of activities

						Renewable resource	Un Renewable resource	Fix cost of each activity					
				EX Method	EX Mode	machinery	human resource	Building Materials	Mec items	Eq	ELC M		
NA	Activity	TIME (DAY)	prerequisite			r1	r2	r3	r4	r5	r6	r7	FC(RIAL)
1	A												
2	B	20		a	1	2	5						200000000
		30 days		b	2	3	5						200000000
3	C	65days	2	a	1	3	15	333.33					1800000000
		70 days		b	2	7	6	333.33					600000000
4	D	25 days	2		1	3	5	20					50000000
5	E	40 days	4		1		7			23.33			200000000
6	F	20 days	5		1		6	10		20			40000000
7	G	20 days	6		1	2	6	50					20000000
8	H	110days		a	1		20	60					60000000
		90 days	3	b	2		12	90					150000000
9	I	40 days	8SS+20d		1		10			24		1000	300000000
10	J	30days	9ss+20d		1		6				50		200000000
11	K	60 days	9SS+10d,8		1		20			50		2000	300000000
12	L	80 days	8,11SS+30d		1		10		6.25				300000000
13	M	20 days	12		1		4		20				100000000
14	N	60 days	8,11,12		1		6				22.5		300000000
15	O	60 days	8,12,11		1		6				20		300000000
16	P	20 days	12,15FF		1		6		16				100000000
17	Q	30 days	4,5,6,7,15		1	3	5		20				1000000000
18	R	110days	12,17	a	1		8		5				200000000
		40 days		b	2		4		16.7				300000000
19	S	60 days	3,14SS+10d,15FF		1		5		10				100000000
20	T	60 days	14FF,15		1		6				10		400000000
21	U	15 days	20,9,18FF,10				20						500000000
22	V	10 days	16,17,18,21,13,19				20						300000000
			m	1500000rial	cr5=	n/day	20000000rial	cr1=					
			divice	10000000rial	cr6=	p/day	3000000rial	cr2=					
	h		m	200000rial	cr7=	m3	5000000rial	cr3=					
				m2	10000000rial	cr4=							

The data were as follows: the ID and topic of each activity, duration of each activity (day), prerequisites of each activity, possible methods and operations to perform each activity, the list of resources, either renewable or fossil fuels, maximum level of available sources, the

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unit cost of each available source, and fixed costs of each activity. The project activities network is provided in Charts 1 and 2.

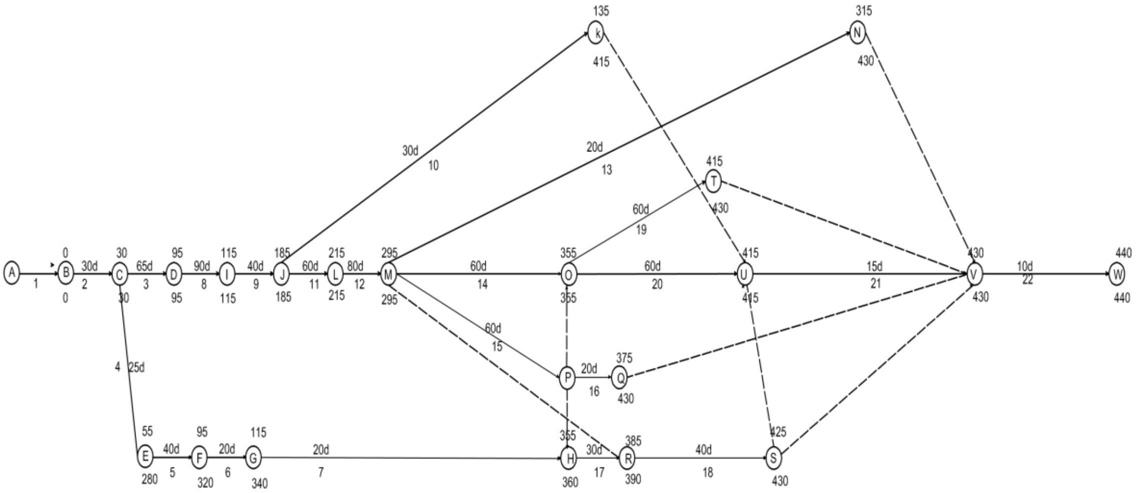

Fig. 1 Network of project activities and duration of activities

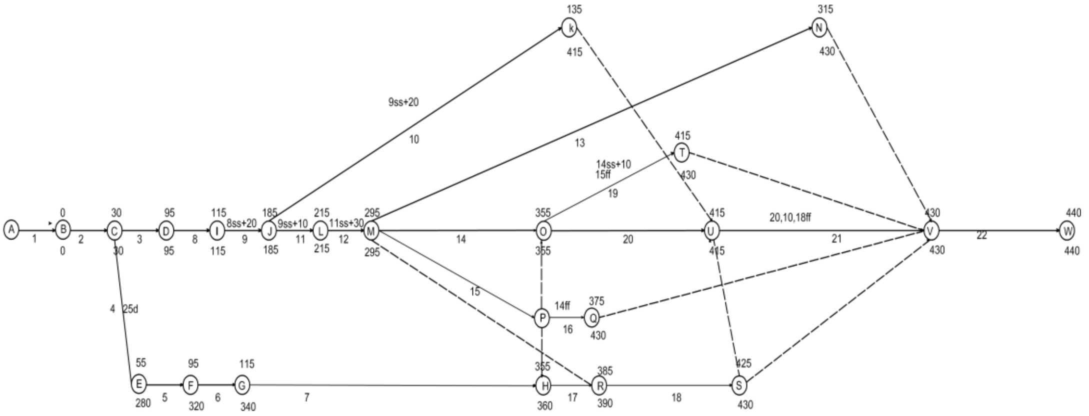

Fig. 2 Network of project activities and relations of activities

Table 4 shows that some activities contained two operational methods, and the most appropriate option was selected. These activities were as follows:

Activity number 2: Excavation, using a bulldozer or excavator

Activity number 3: Skeletons and concrete platforms, using either batching in the construction site or contracting

Activity number 8: Construction of locker room and administrative areas using bricks or Knauf

Activity number 18: preparing the football field using either tartan turf or grass

The applied resources and their level of use are briefly described in the following.

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Table 5 Amount of available resources

Row	Topic	Available resources per day
1	Equipment	3
2	Human resources	30
2	Construction material	340
4	Other construction material	50
5	Mechanical equipment	50
6	Equipment	50
7	Electrical equipment	2000

Parameters adjustment:

In this study, a multi-objective model was used for scheduling the construction project. The PSO method was applied to find the ideal solutions. All analyses were administered by Matlab version 2019b using a computer with a Core i5-2.5GH processor. In the following, we describe the parameters adjustment and their evaluation. In most cases, meta-innovative methods require parameters adjustment to obtain the ideal solution. This goal was achieved by reviewing previous studies (Table 6).

Table 6 Parameters adjustment

Row	Parameter	1	2	3	4	5	6	7	8	9	10	11	12
1	Initial population(max it)	400	500	600	650	700	700	650	650	650	650	650	650
2	repetitions	150	200	250	250	250	300	250	250	250	250	250	250
3	Inertie (w)	1	1	1	1	1	1	1	1	1	1	0.8	0.6
4	self-recognition component coefficient (c_1)	1.5	1	1	1	1	1	1.5	0.6	1	1	1	1
5	Collective-recognition coefficient (c_2)	2	2	2	2	2	2	2	2	1.6	1.4	2	2

The results and model evaluation

After running the model using the PSO algorithm, 150 non-dominated solutions were identified, each of which can be used by project managers based on their needs and importance.

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Table 7 Comparison of solutions provided for target 1 (the lowest project time) at each stage of the program based on parameters adjustment

	Target function 1 T_{min}	Target function 2 C	Target function 3 RLI	Target function 4 NCF	Target function 5 TF
	Time minimization	Homogeneity of daily financial flows	Leveling resources and their minimization	Minimization of negative cash flows	Floatiness maximization
Result1	515	2.555e+9	14.0102	3.1626e+11	1313
Result2	515	2.0907e+9	14.0102	3.1625e+11	1280
Result3	515	2.555e+9	14.0102	3.1625e+11	1333
Result4	515	2.3463e+9	14.0102	3.1525e+11	1314
Result5	518	2.4723e+9	14.0102	3.343e+11	1279
Result6	515	2.0952e+9	14.0102	3.1626e+11	1333
Result7	515	2.3463e+9	14.0102	3.1625e+11	1264
Result8	515	2.2212e+9	14.0102	3.3143e+11	1263
Result9	515	2.5552e+9	14.0102	3.1625e+11	1313
Result10	515	1.9503e+9	14.0102	3.1625e+11	1313
Result11	515	2.1169e+9	14.0102	3.1626e+11	1264
Result12	516	2.0808e+9	14.0102	3.1626e+11	1314

Table 8 Comparison of solutions provided for target 2 (homogeneity of daily financial flows) at each stage of the program based on parameters adjustment

	Target function 1 T_{min}	Target function 2 C	Target function 3 RLI	Target function 4 NCF	Target function 5 TF
	Time minimization	Homogeneity of daily financial flows	Leveling resources and their minimization	Minimization of negative cash flows	Floatiness maximization
Result1	619	1.888e+9	14.0034	3.4106e+11	1009
Result2	637	1.888e+9	14.0034	3.4106e+11	1101
Result3	640	1.888e+9	14.0102	3.3143e+11	1182
Result4	563	1.888e+9	14.0102	3.3143e+11	886
Result5	577	1.888e+9	14.0102	3.3143e+11	1035
Result6	593	1.888e+9	14.0102	3.3143e+11	1045
Result7	635	1.888e+9	14.0034	3.4106e+11	1051
Result8	663	1.888e+9	14.0034	3.4106e+11	1210
Result9	647	1.888e+9	14.0102	3.3143e+11	1177
Result10	652	1.888e+9	14.0034	3.4106e+11	1118
Result11	628	1.888e+9	14.0034	3.41.6e+11	1089
Result12	621	1.888e+9	14.0034	3.4106e+11	1049

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Table 9 Comparison of solutions provided for target 4 (minimization of negative cash flows) at each stage of the program based on parameters adjustment

	Target function 1 T_{min}	Target function 2 C	Target function 3 RLI	Target function 4 NCF	Target function 5 TF
	Time minimization	Homogeneity of daily financial flows	Leveling resources and their minimization	Minimization of negative cash flows	Floatiness maximization
Result1	591	1.889e+9	14.0102	3.162e+11	1045
Result2	614	1.9847e+9	14.0102	3.1625e+11	1006
Result3	570	1.9847e+9	14.0102	3.1625e+11	1068
Result4	695	1.9503e+9	14.0102	3.1625e+11	951
Result5	592	1.8893e+9	14.0102	3.1625e+11	1045
Result6	569	1.9847e+9	14.0102	3.1625e+11	905
Result7	573	1.9847e+9	14.0102	3.1625e+11	1070
Result8	562	1.8893e+9	14.0102	3.1625e+11	1142
Result9	568	1.9847e+9	14.0102	3.1625e+11	1077
Result10	560	1.9503e+9	14.0102	3.1625e+11	1133
Result11	591	1.8893e+9	14.0102	3.1624e+11	1058
Result12	595	1.9503e+9	14.0102	3.1625e+11	813

Table 10 Mean value of obtained solutions based on study goal

	Target function 1 $\boldsymbol{T_{min}}$	Target function 2 C	Target function 3 RLI	Target function 4 NCF	Target function 5 TF
	Time minimization	Homogeneity of daily financial flows	Leveling resources and their minimization	Minimization of negative cash flows	Floatiness maximization
Result1	609	2.030e+9	14.261	3.292e+11	1365
Result2	594	1.993e+9	14.173	3.279e+11	1324
Result3	597	2.026e+9	14.154	3.270e+11	1316
Result4	600	2.004e+9	14.174	3.275e+11	1300
Result5	601	2.046e+9	14.228	3.292e+11	1374
Result6	600	2.0017e+9	14.154	3.256e+11	1321
Result7	594	2.0358e+9	14.200	3.277e+11	1329
Result8	584	1.9983e+9	14.117	3.2684e+11	1329
Result9	603	2.0139e+9	14.115	3.2673e+11	1347
Result10	576	2.0310e+9	14.183	3.2587e+11	1343
Result11	577	2.0471e+9	14.176	3.2779e+11	1326
Result12	604	2.0457e+9	14.218	3.2896e+11	1361

To better understand the findings mentioned above, the values of the best solution number 10 (Table 7), as an instance, are provided in the following figures.

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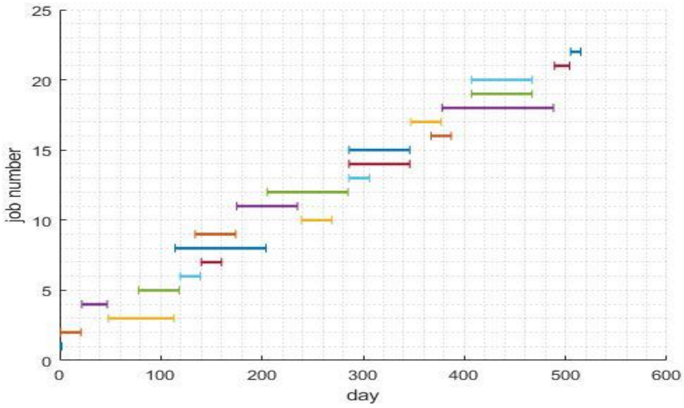

Fig. 3 Project scheduling

Analysis of results

Table 11 contains the best-obtained solutions.

Table 11 The best obtained solutions

Target function	Description	Symbol	Value
1	Minimum time	T_{min}	515
2	Minimum daily financial flow	C	1.888e+9
3	The minimum level of resources	RLI	14.0034
4	Total cash flow of the project	NFS	3.1625e+11
5	Maximum floatiness	TF	1588

A comparison of obtained solutions for solution number 10 is provided in the following.

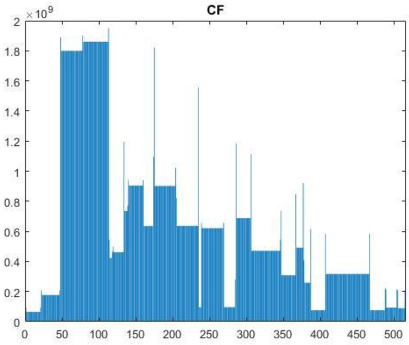

Fig. 4 Project costs based on total and daily costs

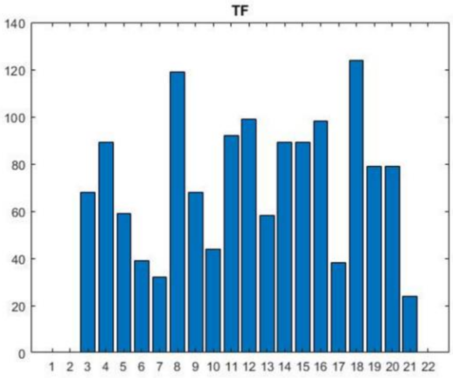

Fig. 5 Floatiness of activities

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Table 12 Parameters used for solution number 10

Parameter	Value
Initial population (max it)	650
Number of repetitions (n pop)	250
Inertia coefficient (w)	1
self-recognition component coefficient (c1)	1
Group-recognition component coefficient (c2)	1.4

Considering that solution 10 is minimized for variables of time and cost and is acceptable for other variables, project managers can consider it. Table 13 was used for two modes of operational algorithm and operational methods, and considering the objectives, the following operational methods were proposed.

Table 13 Selected operational methods for activities with two operational modes

ID	Topic	The operation selected by the algorithm	Description
2	Excavation	Operation 1	Bulldozer
3	Skeletons and concrete platforms	Operation 1	Batching
8	Construction of locker room and administrative area	Operation 2	Knauf
18	preparing the football field	Operation 1	Grass

If we consider the mean value of obtained solutions as the criterion, according to Tables 4 to 9, solution 10 would be acceptable (meantime: 557 days; and cost of 327,990,000,000 Rials). However, as the investigated project is multi-objective, the priority of each objective for managers should be evaluated.

5 Discussion and Conclusion

Project control and scheduling has always been one of the most important issues of project management, which has received the attention of managers more than before. In this article was investigated the importance of parameters such as project time, consumed resources, negative project cash flows, and floating of activities in the control and scheduling of projects, these goals were considered for optimization in the multi-objective mathematical model, and after examining various multi-objective optimization models, The meta-heuristic method of the particle swarm algorithm was chosen due to the speed of calculations. Due to the fact that different implementation methods are proposed for each activity, the ability to use and choose implementation methods was included in the program, and considering the five goals of the model, project managers can choose the optimal solutions according to their priorities.

Resource-constrained Project Scheduling Problem (RCPSP) is an NP-hard problem in which adding limitations of the real world increases its complexity. Therefore, it is not easy to obtain precise solutions. A series of algorithms are provided to address this issue. Although these algorithms do not provide accurate solutions to managers and researchers, they help find the appropriate solution.

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As each project contains different stakeholders, the need for such multi-objective functions to meet the goals of all stakeholders is higher than ever. This is evidently seen in large-scale construction projects, in which stakeholders include investors, managers, consultants, contractors, and operators. It should be noted that each stakeholder has its goals, which sometimes are contradictory. In this study, we tried to include essential goals of various stakeholders, such as minimizing time, minimizing the level of resources, maximizing the utilization of resources, adjusting daily cost balance, reducing cash flows and project costs, and maximizing the floatiness of activities. In addition, various operational methods can be used for each activity based on the goals defined for the algorithm. Employing innovative methods that can solve in the shortest time, which are optimal, is crucial to solving such NP-hard problems. This issue indicates the importance of using meta-innovative algorithms with several benefits. The importance of meta-innovative algorithms roots in the necessity of reaching definitive solutions for complex tasks.

The model solution presented in this study is based on the meta-innovative Particle Swarm Optimization (PSO) method, which is one of the successful collective intelligence methods based on the random production of the initial population inspired by the movement of flock birds and the mass movement of fish to find food. One of its essential advantages is simplicity and memory utilization, which saves optimal solutions for further usage by other particles.

The PSO algorithm, which benefited from various parameters and adjustments, indicated the high capability of the algorithm in simultaneous optimization and providing appropriate solutions for all goals. The obtained solutions were different in each cycle, and finally, the best solution was obtained for each function. Considering the heterogeneity of goals and their contradictory nature, in some cases, managers and researchers should select the most appropriate ones by considering the priorities and the context.

Some solutions contain the most optimal values for two or three objective functions while are acceptable for the rest, which is an essential advantage of this algorithm, allowing managers to select the best one. For instance, some solutions contained two objective functions that are highly important for stakeholders, including minimization of project time and cost, while others were excellent and acceptable. The use of advanced methods prevents unnecessary costs caused by delays or increased price of resources, or any direct and direct harmful effect. It also optimizes the use of resources, leveling appropriate resources, and administering appropriate operational methods for those with more than one available method to achieve the best performance.

6 Suggestions for future research

The proposed model in this research has potential for its development, which is discussed below:

1- Inclusion of other goals in the model: Considering goals such as reducing existing risks for projects in the objective function.

2- Considering the state of interruption in the implementation of activities:

One of the features that this project can have is to consider the existence of interruption mode in the activities in such a way that in case of lack of resources, any activity can be stopped at the time of execution and continue at another time when its resources are provided.

3- Examining and solving the model with other existing algorithms:

Due to the existence of various algorithms to solve multi-objective project scheduling problems with limited resources, it is possible to solve the model with other algorithms and compare their results with each other.

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