Multiobjective Project Scheduling with Multiple Compression Capabilities of the Multistate Activities with Project Reliability Approach using the Metaheuristic Algorithm

Seyed Ahmad Shayannia

Department of Industrial Management, Firoozkooh Branch, Islamic Azad University, Firoozkooh, Iran

Correspondence should be addressed to Seyed Ahmad Shayannia; sheibat@yahoo.com

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We examine the time-cost-reliability-project balance of the project by considering the limitations of renewable and nonrenewable resources and performing multistate group activities in the same conditions and with the possibility of multiple compression activities. This study aimed to select the best mode for conducting actions in each subset and find the best execution method by determining the number of compression time units of actions to maximize project reliability and minimize project completion risk, time, and cost. Drilling projects will also be implemented for evaluation in the Azar oil field. The exact Epsilon Limitation method was used to solve this problem in low dimensions. The combined genetic metaheuristic algorithm and particle swarming were used to solve high dimensions problems. The low-dimensional Epsilon solution method could clearly balance the objective functions. Also, the Taguchi experimental design method was used to adjust the parameters of the problem algorithm. The correct value of the algorithm parameters is also specified. Based on the results, the hybrid metaheuristic algorithm has less solution time than the exact method. In high dimensions, as it was observed, GAMS software could not solve the problem. Still, the hybrid metaheuristic algorithm solved the problem well in high dimensions.

1. Introduction

This is a temporary effort aimed at producing a unique product. For each project, a temporary organization is formed of individuals, and resources (budget, human resources, machinery, etc.) are provided to produce a unique product with the requirements set in the framework. Project frameworks or limitations s are usually divided into four items: scope, time, cost, and quality, but there are other things to consider. Together, these four elements form the classic triangle of the project [1]. In today’s world, most large organizations are carrying out several projects simultaneously to produce a new product or service following the goals and policies of the organization. Sometimes, the pressure to complete on time by the project budget and maintain competitive advantage has led organizations to develop and implement project management processes [2]. Thus, organizations are shifting from traditional pragmatic structures to project-oriented ones, which must complete projects with clear but immediate goals according to the agreed time in a competitive environment with limited resources in mind. Increasing the project completion time compared to the planned time is one of the significant problems of project implementation. It increases its cost and economic inefficiency and causes delays in completing work and poor project managers in front of customers. Improper and irrational project scheduling will cause many problems such as errors in cost estimation and project budgeting, making mistakes in decision-making and prioritizing projects, incurring late costs and depriving the employer of trust in contracts, lack of attention to resource feasibility, failure to control the project, and inconsistencies in project progress reports. To prevent possible problems of projects, before starting the project, we should study the feasibility study according to project management knowledge and consider the limitations.
The project management knowledge set will help to know how to properly implement each of the project management actions, what steps to take at what times, and with whose participation.

1.1. Problem Statement. The critical path method for solving project planning problems was introduced in the late 1950s. In the calculations of this method, it is assumed that all activities can be performed at their expected and usual time. The project may need to be completed even earlier than planned in some cases. The time of several activities should be reduced to achieve the time of completion sooner. This reduction in time is accompanied by an increase in labor resources and expenditure, called performing impact or compression of activity time.

At the same time, carrying out activities in less time increases the quality of the activities and the project’s risk and reliability. It is challenging for managers to make a complete and accurate decision regarding these benefits and penalties. Therefore, pay attention to the problems of time-cost balance. The general state of time-cost balance problems is divided into two categories, continuous and discrete, based on the form of the direct cost function of the activity. Under continuous functions, the shape of the function may be linear, convex, or concave. In discrete time-cost balance problems, also known as multimode problems, resources are available in discrete units. The goal is to allocate the best execution mode and resources needed for project activities, at least promptly. In 1995 and 1998, a particular state of the multimodal problem was discussed. At that time, the activity was considered a function of resource needs (State choice), and the amount of time accelerated the reduction of time through increased direct costs. Indeed, after having selected one execution mode out of several modes and assigned it to an activity, it is possible to reduce the time of this activity by incurring more costs. This means that the time and cost of the activity depend not only on the choice of mode but also on the choice of time during a mode. These issues are referred to as multistate compression issues [3, 4].

In this study, as opposed to previous studies, in which only one of the normal or intensive conditions might be selected, a set of correct time units will be used to determine the amount of activity compression. The numbers in this set start from zero for the usual execution method and end with adding one unit of compression periods to a specific value (maximum amount of compression) for the compact execution method. In fact, this will determine the number of units that accelerate the activity’s execution time, despite selecting the normal or intensive execution method in the mode assigned to each activity. All activity modes’ assignments are done independently in the multimodal problems discussed so far. This means assigning a mode to action in a project that includes a set of activities does not necessarily force any other activity to be performed in a particular mode. In practice, however, there may be situations where certain activities belong and must be completed in the same way. This problem is known as problems with the same state. Therefore, in this study, to bring the proposed model closer to real-world projects, by dividing project activities into separate subdivisions and defining multiple execution modes for each subset of activities, those activities in the same subset are performed. Also, unlike previous research, here, considering the ability to compress multiple modes, none of the activities in the group will be required to be performed regularly or intensively and will only have the same execution mode [5–7].

Generally, projects are trained to address a set of needs, and the goal of project managers is to guide and control the project in its main direction to achieve the predetermined goals. Many goal functions are often considered in projects for various reasons. One of the most important reasons for this is the presence of different stakeholder groups in the project. Among the most important goals that have been considered in this field in different ways, we can mention the optimization of project completion time, project cost, quality, net present value, safety, flexibility in scheduling, etc. In these issues, different limitations are considered, such as resource limitations (renewable and nonrenewable) and prerequisite and postrequisite relationships. However, less attention has been paid to objectives such as reliability and risk in project management issues among the mentioned objective functions. To increase the reliability of the project, we try to select the modes of execution of the activities so that the activity can be completed on time and completely. For example, it is assumed that different levels of technology, such as hand tools, semiautomatic and all-automatic, are available to perform an activity.

On the other hand, the reliability of using each level of technology is different. Factors such as fatigue and error of human resources, lack of timely human resources in the workplace, improper transportation, incorrect loading and unloading, device failure, and improper maintenance and repair can reduce reliability. Therefore, the type of execution mode selected can affect the time cost and the reliability of the activity. On the other hand, the risk of carrying out project activities can affect one or more of the project objectives. The risk may have one or more causes, such as the need for a license and limited resources or other aspects of the project environment, such as poor project management practices or reliance on outside specialists that are not controllable. Therefore, the type of execution mode selected can affect the activity’s time, cost, reliability, and risk. Because of the above, in this study, we try for the first time to simultaneously optimize the goals of time, cost, reliability, and risk of project implementation, given their undeniable importance in today’s projects. In addition, the issue of multiple compression modes and problems of the same state is rarely considered due to the complexity of the problem. Therefore, in this study, for the first time, we concern the issue of time balance-cost-reliability-project risk by considering the limitations of renewable and nonrenewable resources and performing multimode group activities in the same conditions and with the possibility of multiple compression activities. The purpose is to select the best mode for executing the activities in each subset and find the best execution method by determining the number of compression time units of actions to maximize project reliability and minimize risk, time, and cost of project completion. Also, in this research, drilling projects will be...
implemented for evaluation in the Azar oil field. Since the scheduling problem is an NP-HARD problem, a multi-objective genetic algorithm will solve it.

2. Literature Review

Koo et al. [8] introduced an integrated multiobjective optimization model to provide a set of optimal solutions based on Pareto front concepts in six stages. These six steps are as follows: (1) problem statement, (2) definition of optimization goals, (3) data structure creation, (4) standardization of optimization goals, (5) definition of the fit function, and (6) introduction of genetic algorithm. A case study on the issue of the time-cost balance of construction and instrument was analyzed to evaluate the reliability of the proposed model. The results of this research can be used in the following cases: (1) determining the project completion time, (2) selection of activities to be completed, (3) evaluation of the project's reliability, (4) evaluation of the project's cost, (5) definition of the fit function, and (6) introduction of genetic algorithm.

Safari et al. [9] have proposed a triobjective mathematical model for the Transportation-Location-Routing problem. The model considers a three-echelon supply chain and aims to minimize total costs, maximize the minimum reliability of the traveled routes, and establish a well-balanced set of routes. In order to solve the proposed model, four metaheuristic algorithms, including Multiobjective Grey Wolf Optimizer (MOGWO), Multiobjective Water Cycle Algorithm (MOWCA), Multiobjective Particle Swarm Optimization (MOPSO), and Nondominated Sorting Genetic Algorithm-II (NSGA-II) are developed. The performance of the algorithms is evaluated by solving various test problems in small, medium, and large scale. Four performance measures, including Diversity, Hypervolume, Number of Nondominated Solutions, and CPU-Time, are considered to evaluate the effectiveness of the algorithms. In the end, the superior algorithm is determined by Technique for Order of Preference by Similarity to Ideal Solution method.

Paryzad and Pour [12] have balanced the project’s risk, quality, time, and cost with the help of the dolphin technique. This paper presents the dolphin group hunting algorithm as a new evolutionary optimization method. The proposed algorithm is inspired by intelligent and group hunting of dolphins. In this method, a dolphin that finds its prey using its voice reflection is selected as its leader and then informs the other dolphins of the prey's position. By circling the prey and adjusting their position relative to the leader, the dolphins bring the prey closer to the water's surface in the form of a cone and hunt it. The experimental results show that the proposed algorithm achieves the optimal answer faster than other algorithms.

Zheng [13] has compared time-cost-environment balance with combining genetic algorithms. His goal is to minimize the total project time to minimize delay costs and minimize environmental impacts. Since the exact solution methods for this problem were not very efficient, for this purpose, he used the method of combined genetic metaheuristic algorithm, which in the above dimensions has been well converged to the optimal solution. Zhang and Xing [14] have examined the issue of project scheduling with a balance of profit and time. Their research considered several discrete times with 4 payment methods where the final profit depended on their completion time because as the project time decreases, the cost will decrease. Thus, the profit will increase, and since the issue was an NP-hard issue, He used the neighborhood search method to solve the problem. Rahimi et al. [15] investigated the problem of scheduling oil and gas projects with a cost-time-quality balance approach to minimize the total project time and maximize quality. The issue was examined in conditions of uncertainty. They investigated the problem with a multiobjective solution and Pareto front generation approach and used fuzzy theory to deal with the uncertainty of the parameters. Askarifard et al. [16] examined the balance between project time and cost, the Bayesian approach to updating project time, and cost estimation, taking into account cost, time, and resource limitations, under conditions of uncertainty. They also used a metaheuristic solution to the problem, thus saving considerable time relative to the exact solution.

3. Model Assumptions

The assumptions considered in the mathematical model of the problem are as follows:

(i) Customer determines the initial scope of the project
(ii) Client reviews the initial schedule at the tender time and accordingly requests the contractor to reduce the project completion time
(iii) There are resource limitations

3.1. Model Symbols. The symbols considered in the mathematical model of the problem are as follows:

\( i \): prerequisite activity symbol

\( j \): activity symbol
3.2. Model Parameters. The parameters considered in the mathematical model of the problem are as follows:

- \( PR_{jn} \): revenue from the implementation of activity \( j \) in project \( n \)
- \( C_{jn} \): cost of increasing or decreasing the delay of a unit of time in activity \( j \) in project \( n \)
- \( d_{jn} \): duration of activity \( j \) in project \( n \)
- \( TR_{jn}^{max} \): maximum time unit allowed for activity \( j \) in project \( n \)
- \( f_{0n} \): project completion time specified by the client in the project \( n \)
- \( ss_{ijn}^{min} \): minimum time between the end of \( i \) and the beginning of activity \( j \) in project \( n \)
- \( SS_{ijn} \): minimum time between the start of activity \( i \) and the end of activity \( j \) in project \( n \)
- \( ST_{ijn}^{min} \): minimum time between the start of activity \( i \) and the end of activity \( j \) in project \( n \)
- \( P_{jn} \): probability of project risk by reducing \( t \) time in activity \( j \) in project \( n \)
- \( lr_{jtn} \): magnitude of the impact of risk on activity \( j \) is affected by \( r \) with \( t \) units of delay in project \( n \).

3.3. Decision Variables. The decision variables of the mathematical model of the research area follow:

- \( y_{jtn} \): if activity \( j \) is delayed by project \( t \) in project \( n \), it takes a value of one, otherwise zero
- \( ES_{jn} \): the earliest time to start activity \( j \) in project \( n \)
- \( LF_{jn} \): the latest end time of activity \( j \) in project \( n \)

3.4. Mathematical Model of the Problem. The mathematical model proposed in this research is as follows:

\[
\text{Min} Z_1 = \sum_{n=1}^{N} \sum_{j=1}^{J} \sum_{t=1}^{TR_{jn}^{max}} t y_{jtn},
\]

(1)

\[
\text{min} Z_2 = \sum_{n=1}^{N} \sum_{j=1}^{J} \sum_{t=1}^{TR_{jn}^{max}} \sum_{r=1}^{R} P_{jn} lr_{jtn} y_{jtn},
\]

(2)

\[
\text{min} Z_3 = \sum_{n=1}^{N} \sum_{j=1}^{J} \sum_{t=1}^{TR_{jn}^{max}} (t C_{jn} y_{jtn}),
\]

(3)

\[
\text{max} Z_4 = \sum_{n=1}^{N} \sum_{j=1}^{J} \sum_{t=1}^{TR_{jn}^{max}} \sum_{r=1}^{R} P_{jn} lr_{jtn} y_{jtn},
\]

(4)

s.t. \( LF_{in} = f_{0n} \),

(5)

\[
\sum_{t=1}^{TR_{jn}^{max}} y_{jtn} \leq 1, \quad \forall j, n,
\]

(6)

\[
LF_{jn} - ES_{jn} \geq \left( d_{jn} - \sum_{t=1}^{TR_{jn}^{max}} t y_{jtn} \right), \quad \forall j, n,
\]

(7)

\[
ES_{jn} - ES_{in} \geq \left( d_{jn} - \sum_{t=1}^{TR_{jn}^{max}} t y_{jtn} \right) + ES_{ijn}^{min}, \quad \forall i, j, n,
\]

(8)

\[
LF_{kn} - LF_{jn} \geq \left( d_{kn} - \sum_{t=1}^{TR_{jn}^{max}} t y_{jtn} \right) + ES_{jkn}^{min}, \quad \forall j, k, n,
\]

(9)
\[
\begin{align*}
\text{ES}_{jn} - \text{ES}_{in} & \geq \text{SS}^\text{min}_{ijn}, \quad \forall i, j, n, \\
\text{LF}_{kn} - \text{LF}_{jn} & \geq \left( d_{kn} - \sum_{t=1}^{\text{TR}^\text{max}_{jn}} t \cdot y_{kn} \right) - \left( d_{jn} - \sum_{t=1}^{\text{TR}^\text{max}_{jn}} t \cdot y_{kn} \right) + \text{SS}^\text{min}_{jk}, \quad \forall j, k, n, \\
\text{ES}_{jn} - \text{ES}_{in} & \geq \left( d_{jn} - \sum_{t=1}^{\text{TR}^\text{max}_{jn}} t \cdot y_{jn} \right) - \left( d_{jn} - \sum_{t=1}^{\text{TR}^\text{max}_{jn}} t \cdot y_{jn} \right) + \text{FF}^\text{min}_{jkn}, \quad \forall j, k, n, \\
\text{LF}_{kn} - \text{LF}_{jn} & \geq \text{FF}^\text{min}_{jkn}, \quad \forall j, k, n, \\
\text{ES}_{jn} - \text{ES}_{in} & \geq \text{SF}^\text{min}_{ijn} - d_{jn} - \sum_{t=1}^{\text{TR}^\text{max}_{jn}} t \cdot y_{jn}, \quad \forall j, k, n, \\
\text{LF}_{kn} - \text{LF}_{jn} & \geq \text{SF}^\text{min}_{jkn} - d_{jn} - \sum_{t=1}^{\text{TR}^\text{max}_{jn}} t \cdot y_{jn}, \quad \forall j, k, n, \\
\text{LF}_{jn}, \text{ES}_{jn} & \geq 0, \quad \forall j, n, \\
y_{jn} & \in \{0, 1\}, \quad \forall j, t, n.
\end{align*}
\]

As can be seen, there are four objectives of the study. The first objective function (1) minimizes delays in implementing each project activity. This function is obtained by multiplying the variables zero and one based on whether or not there is a delay in the execution of activity \( j \) during the delay time \( t \). The model’s second function (2) also minimizes the safety cost incurred in obtaining delays in each project’s implementation activities. The third objective function (3) minimizes the cost of activities in each project. The objective function (4) also maximizes the quality of activities in each project. Limitation (5) specifies the time frame set by the client for each project. In fact, this limitation ensures that the entire project is completed within the maximum time set by the customer for each project. Limitation (6) ensures that if a delay occurs in an activity, it will occur only within one of the timeframes specified for each project. Limitations (7) to (15) calculate the project’s critical time and allocate the appropriate start and end time for each activity for each project. Limitations (8) and (9) indicate FS relationships, limits (10) and (11) indicate SS relationships, limits (12) and (13) indicate FF relationships, and limitations (14) and (15) indicate SF relationships between activities. Limitations (16) and (17) also determine the range of decision variables.

### 4. Case Study of the Research

Azar oil anticline is located in Anaran exploration block in Ilam province (southwestern Iran) and near the Iran-Iraq border. Azar structure along the northwest-southeast has a length of about 5.36 km on the horizon of Ilam, located approximately 13.5 km in Iran.

4.1. **Central Operation Facility Project (for Model Validation).**

This project includes all engineering services, procurement, and purchase of goods, construction, and installation required for the daily production of 65,000 barrels of crude oil and the extraction of 78 million cubic feet of gas per day. Production fluid is collected from 17 production wells in Manifold to collect common fluid to enter two separate production trains. After the fluid passes through the precooling unit, it passes through two three-stage separators to completely separate the gas and water that accompany it. The fluid then enters the desalination unit and the sulfur separator to remove \( \text{H}_2\text{S} \). The stabilized oil is then cooled in an air conditioner and transferred to an On-Spec storage tank via a shared header. Three booster pumps and three main pumps transfer stored crude oil to Cheshmeh Khosh production center located in Dehloran city through a dedicated oil transfer pipeline. The produced gas is first dried in two dewatering routes. It enters the two gas pressure boosting routes through a common header, each containing three gas pressure boosting compressors, until after the necessary boosting through the gas transmission pipeline for delivery.
Finally, it is to be sent to the NGL-3100 facility, Dehloran production center. The Central Operation Facility (CPF) will naturally generate and transport 65,000 barrels of crude oil per day. However, this complex is designed for a daily production capacity of 51,500 barrels of oil and 78 million cubic feet of gas per day, which can process 23,000 barrels of wastewater for reinjection into the tank.

The EPC contractor of this project is Jahanpars Engineering and Construction Company. The description of their activities and relationships is as described in Table 1.

According to the activities and their prerequisite relationships in Table 2, the critical path of CPM can be shown in Figure 1.

Also, other problem parameters are randomly presented. After solving the problem, the results are presented in the following tables by helping the GAMS software and Cplex 22.1.1 solver in a personal system with 3.2 GHz processing power and 4Gb of random memory. It is noteworthy that the software execution time equals 85 seconds, and the computational gap equals zero. The Parthian front of the problem is represented by the values in Table 3.

According to the information in Table 3, it can be seen that none of the points overcomes the point or other points. Therefore, the Pareto front is properly formed. In Figure 2, the resulting Pareto front graphic can be seen.

Figure 2 shows that safety has increased with increasing project delays. This is logical because the longer the delay in a project, the lower the project risk, and as a result, the project safety will increase.

In Figure 3, the enclosed page shows the Pareto front members. Of course, not all members can be identified; because of the continuity of the values obtained in each function, all points between the two points of the front can be considered a member of the Pareto front. Also, from this figure, the shapes depicted on each target function page can be well understood in two dimensions. The critical point in analyzing and using the answers obtained from solving multiobjective problems from the Pareto front format is selecting one of the front points as the final answer for implementation in the system under study.

4.2. Sensitivity Analysis. To validate and analyze the proposed model, sensitivity to some parameters is measured. In fact, it is examined how the objective functions change by changing the desired parameters and to what extent our expectations from the model correspond to the results. This research investigates the sensitivity analysis of the mentioned dimensions to the risk, delay, and time of activities.

### Table 1: Time and description of the activity of the central operation facilities project.

| Activity name | Activity description | Prerequisite for activity | Activity time | Time | Floating time |
|---------------|----------------------|---------------------------|---------------|------|---------------|
| A             | Engineering          | —                         | 0             | 0    | 0             |
| B             | Procurement          | 4                         | 4             | 5    | 7             |
| C             | Geotechnical & soil mechanical test | 4 | 4 | 7 | 7 | 0 |
| D             | Civil & building     | 7                         | 7             | 10   | 10            |
| E             | Steel structure fabrication & erection | 10 | 10 | 12 | 0 |
| F             | Tank fabrication & erection | 10 | 10 | 12 | 0 |
| G             | Mechanical installation | 12                         | 12            | 15   | 15            |
| H             | Piping               | 15                        | 15            | 19   | 19            |
| I             | Cathodic protection  | 15                        | 15            | 17   | 17            |
| J             | Electrical           | 15                        | 15            | 18   | 18            |
| K             | Telecommunication    | 19                        | 19            | 21   | 21            |
| L             | Instrumentation      | 21                        | 21            | 27   | 27            |
| M             | Final documentation  | L                         | 27            | 34   | 34            |
| N             | Precommissioning     | M                         | 34            | 36   | 36            |
| O             | Commissioning        | N                         | 36            | 38   | 38            |

### Table 2: The value of the problem parameters in GAMS software.

| PR_{jn} | Uniform distribution between (8000–5000) |
|---------|----------------------------------------|
| C_{jn}  | Uniform distribution between (500-100)  |
| d_{jn}  | Uniform distribution between (10-2)    |
| TR_{max} | Uniform distribution between (3-1)   |
| f_{min} | Uniform distribution between (2-1)    |
| s_{min} | Uniform distribution between (2-1)    |
| f_{min} | Uniform distribution between (2-1)    |
| s_{min} | Uniform distribution between (2-1)    |
| P_{jn}  | Uniform distribution between (1-0)    |

Figure 1: The time and project critical path.
4.2.1. Analysis of the Sensitivity of the Problem to the Delay Parameter. To see the effect of delay on other objectives, we need to modify it to see its effect on other functions. It is necessary to examine the changes in the value of the cost parameter on all three objective functions, which are specified in Table 4. As can be seen from the table, with increasing safety delay, the cost increases and the cost and quality increase, but safety and quality take precedence over cost.

| First object function (amount of delay) | Second objective function (safety) | Third objective function (cost) | Fourth objective function (quality) |
|----------------------------------------|-----------------------------------|---------------------------------|-----------------------------------|
| 39                                     | 6.54                              | 120                             | 0.8                               |
| 34                                     | 6.32                              | 110                             | 0.8                               |
| 30                                     | 5.98                              | 100                             | 0.8                               |
| 29                                     | 5.96                              | 95                              | 0.8                               |
| 28                                     | 5.65                              | 89                              | 0.8                               |
| 26                                     | 5.42                              | 85                              | 0.8                               |
| 25                                     | 5.36                              | 83                              | 0.8                               |
| 24                                     | 5.32                              | 80                              | 0.8                               |
| 23                                     | 4.65                              | 82                              | 0.8                               |
| 22                                     | 4.5                               | 80                              | 0.7                               |

4.2.2. Analyzing the Sensitivity of the Problem to the Failure of Activities. Because failure occurs in time units, we must evaluate the failure rate by the amount of safety and the project's cost.

For the delay rate, we will examine the values of 5, 10, 15, and 20 days. As shown in Table 5, the project's safety increases with increasing latency.

Therefore, the amount of profit has decreased (cost increases), which indicates that the model's logic works properly and the optimal level is the least risk and the least delay to achieve maximum profit.

4.2.3. Sensitivity Analysis of the Problem of Changing the Time of Activities. According to the research's first chapter,
we are looking for what effect this transfer will have on the risk and profit of the project if the customer requests delivery of the work from the contractor earlier than the due date. To investigate this question in the project, we assume that the customer wants us to deliver the project in 36 working days instead of 38 working days, so we must examine what effect this change will have, resulting in Table 6.

As can be seen in Table 6, reducing the total project time from 38 working days to 36 working days in 5 different repetitions increased cost and reduced safety, which is logical. It depends on the client which one to choose between cost and safety and early project delivery, but as is clear in the mathematical research model, most projects always have delays. It seems logical that the customer should request a reduction of the delay instead of requesting a reduction of the project time, which was clearly shown in the results that the risk decreases, and the project’s profit increases.

4.3. Computational Results of the Metaheuristic Algorithm.

To solve the algorithm, we need the optimal parameters of the algorithm, which will be performed according to the design of the Taguchi experiment, which is specified below these experiments.

4.3.1. Design of Experiments. One of the experimental design objectives is to observe and identify output changes through conscious changes in process entry variables. There are several ways to design an experiment.

One of the first methods proposed in this field was the factorial method, which obtained the number of experiments by \( N = L_m \). The main drawback of this method was that if there are many variables, the number of experiments will be vast, and this issue is not cost-effective in terms of time and cost. So, they thought of finding ways to reduce the number of experiments. One of these modifications was the Taguchi method, which we want to explain.

This method, which is a strategy to improve the quality of the process and achieve an enhanced product using the test design method, was first introduced by a Japanese engineer named Genichi Taguchi in 1986. This method is derived from the design of a fraction of factors. The design is organized based on the minimum resources, time, and the number of possible experiments. The reasons for the efficiency of this method for the use of researchers and engineers can be named as follows:

(i) Minimum tests
(ii) Ability to check the effectiveness of the parameters
(iii) Ability to analyze the signal to noise
(iv) Determine the optimal levels of the selected levels

The Taguchi method has made it possible to provide this vital information with a much smaller number of experiments and experiences. Taguchi developed a family of fractional factor schemes used in various applications.

(1) Standard method of analysis of variance (ANOVA)
(2) Use a signal-to-noise ratio (S/N)

The value of S/N expresses the degree of scatter around a specific value or, in other words, how our answers have changed between several experiments.

How do we know which value is better? There are 3 relationships, each used to obtain this value.

In the Taguchi method, a loss function calculates the changes between the results and the desired value, and this function has different modes depending on the problem conditions.

(i) A smaller value is best: \( SB = 1/n \sum (y_i)^2 \)
(ii) Larger amount is best: \( LB = 1/n \sum (1/y_i)^2 \)
(iii) Nominal size is the best: \( NB = 1/n \sum (y_i - y_0)^2 \)

In these formulas, \( n \) number of iterations and \( y \) outputs have been measured. It should be noted that, in this research, we have used the signal-to-noise method. This research seems necessary to optimally adjust the following parameters for the designed algorithm: number of replicates, initial population size, \( p(c) \) intersection, and \( p(m) \) mutation. For this purpose, first, the algorithm is implemented for a problem with suitable dimensions under 5 scenarios according to Table 7, and the mentioned more important factors are analyzed. The results are then used to fine-tune the parameters. In this method, the value of the resulting objective function must be normalized, which in this study
uses the RPD method, which is calculated by the following formula.

$$\text{RPD} = \frac{|\text{BestSol} - \text{MethodSol}|}{|\text{BestSol}|} \times 100$$  \hspace{1cm} (18)

To use the Taguchi method, it is first calculated according to the number of factors, the number of levels (scenarios), and the number of times the algorithm is executed. Figure 4 shows the appropriate number of times the algorithm is executed, calculated by Minitab16 software.

According to the software output, since the test is performed for 4 factors in 5 different scenarios, so the number of runs must be equal to 25, which is according to Table 8.

For example, row 5 refers to the fifth run of the test. The number of generations is selected from Scenario 1 and the remaining parameters from Scenario 5, or as another example in row 20, representing the twentieth time the test is performed. The number of generations is selected from Scenario 4, the population size from Scenario 5, the probability of occurrence of the intersection operator from Scenario 3, and the probability of the mutation operator from Scenario 1. Similarly, all tests are performed according to Table 8, and the results are reported. Because the best response is reported at different algorithm times, the results may be the same based on all scenarios. But parameters such as the number of generations can greatly impact the execution time of the algorithm. Therefore, in the report of the algorithm response, in the iterations required for the Taguchi method and the final response of the algorithm, the execution time is also included and is directly added to the objective function.

4.3.2. Results of Taguchi Experiments to Determine the Optimal Value of the Parameter. To examine the parameters of the genetic algorithm, we must obtain the optimal value of the parameters, which was done by designing an experiment using the Taguchi method, and the results have been determined.

In Figure 5, for the factor number of generations, Scenario 2, the population of Scenario 1, the probability of occurrence of the Scenario 2 intersection operator, and the
probability of Scenario 3 mutation are at the lowest level. The factors are shown according to Figure 6.

Therefore, the best combination proposed by this method is Table 9.

It can also be seen that the greatest effect on the responses reported by the algorithm is due to the population size factor.

4.4. Evaluating the Performance of Algorithms. In this section, the numerical example is designed according to real-world conditions. The results of solving the mathematical model and the proposed algorithms are presented in Table 10. It is noteworthy that the results presented for the algorithms are the best answer among the 10 independent implementations. It should be noted that since the Epsilon method has a limit of 100 repetitions for the problem, it is reported that the first answer of Parthian point takes 55 seconds to check the answer of the first point, but solving every 100 points will take about 5500 seconds. Therefore, in the timetable, the first output is considered.
According to the presented results, it is observed that, in small-dimensional examples, the results of solving the mathematical model and the proposed algorithms have zero computational gaps. This indicates the high efficiency of the proposed algorithms in obtaining the final answers. Gradually, with increasing dimensions of the problem, GAMS software could not solve the problem, so in large examples, the mathematical model could not solve the problem, and only the proposed algorithms provided answers. The quality of the answers provided by the algorithms in high dimensions can not be definitively commented. However, considering the proximity of the answers of both algorithms to each other and the zero computational gap in small dimensions, we can hope that the answers provided in high dimensions are of good quality.

4.5. Algorithm Sensitivity Analysis. To analyze the algorithm’s sensitivity, we must analyze the online criteria of the algorithm, such as the convergence rate of the algorithm concerning the iterations of the problem and the time to reach the final answer.

As shown in Figure 7, this problem has reached convergence in the same initial iterations. It shows that the algorithm has reached the optimal convergent solution very quickly, which indicates the algorithm’s efficiency. As shown in Figure 8, the time ratio of GAMS software is much higher than MATLAB software, which indicates that the algorithm is better.

5. Conclusion

Cost management is the main structure for achieving strategic goals. Cost is created by consuming resources and is the same resources sacrificed to gain value. In this process, to save resources and costs, all costly activities that do not produce value must be eliminated, and value-added activities performed in parallel elsewhere must be combined. Also, those activities are added to the activities of the organization in a way to complete and improve the quality of services.

In this research, the problem of three-objective linear project scheduling has been investigated. In the first objective function, we tried to minimize the amount of delay, and in the second objective, we tried to minimize the amount of risk. Also, in the third objective function, we tried to maximize the profit. The exact Epsilon constraint method...
was used to solve this problem in low dimensions. The combined genetic metaheuristic algorithm and particle swarming were used to solve the problem in high dimensions. The low-dimensional Epsilon solution method was able to show the balance between the objective functions well, and examples with different dimensions for the problem were examined. Also, the project’s critical path was described for the solved examples. Since the three parameters of delay, risk, and profit were reviewed to analyze the sensitivity of the problem, their relationships were examined in two-dimensional and three-dimensional. Taguchi’s experimental design method was also used to adjust the parameters of the problem algorithm to determine the correct value of the algorithm parameters. The results examined in Chapter 4 show that the hybrid metaheuristic algorithm has less solution time than the exact method. In high dimensions, as observed, GAMS software could not solve the problem, but the hybrid metaheuristic algorithm could solve the problem in high dimensions.

**Data Availability**

The data used to support the findings of this study are available within the article.

**Conflicts of Interest**

The authors declare that they have no conflicts of interest.

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