Investigating the impacts of human factors of learning, forgetfulness and fatigue and refreshment on staff scheduling

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Abstract

The present study has investigated the impacts of human factors of learning, forgetfulness and fatigue and refreshment on staff scheduling. It aims to present a mathematical model for staff scheduling so that workforce costs are minimized and the factors of learning, forgetfulness and fatigue of employees, which affect their performance and enhance their efficiency, are taken into account. Parameters of the proposed model comprise the fixed and variable costs of worker assignment, the individual's production rate at different times of work shift, the forgetfulness parameter (which indicates the degree to which a person forgets the skill in performing a task), the learning rate, the amount of time away from work and so on. The variables of the proposed model also indicate worker assignment to the work shifts. After validating the proposed model, several problems have been generated in different dimensions and have been solved by GAMS software. Further, to solve high-dimensional problems, a genetic algorithm was developed, by which the problem was solved in various dimensions. The algorithm accuracy was examined by comparing its results with the exact solution results and its problem-solving ability was also evaluated using the generation of problems in various dimensions and their solutions.

Keywords: Human factors, learning, forgetfulness, fatigue, staff scheduling

Resumo

O presente estudo investigou os impactos de fatores humanos de aprendizado, esquecimento, fadiga e descanso na programação da equipe. O objetivo é apresentar um modelo matemático para a programação da equipe, a fim de minimizar os custos da força de trabalho e levar em consideração os fatores de aprendizado, esquecimento e fadiga dos funcionários, que afetam seu desempenho e aprimoram sua eficiência. Os parâmetros do modelo proposto compreendem os custos fixos e variáveis da atribuição do trabalhador, a taxa de produção do indivíduo em diferentes horários do turno de trabalho, o parâmetro do esquecimento (que indica o grau em que uma pessoa esquece a habilidade na execução de uma tarefa), a taxa de aprendizado, a quantidade de tempo fora do trabalho e assim por diante. As variáveis do modelo proposto também indicam a atribuição de trabalhadores aos turnos de trabalho. Após a validação do modelo proposto, vários problemas foram gerados em diferentes dimensões e foram resolvidos pelo software GAMS. Além disso, para resolver problemas de alta dimensão, foi desenvolvido um algoritmo genético, pelo qual o problema foi resolvido em várias dimensões. A precisão do algoritmo foi examinada comparando seus resultados com os resultados exatos da solução e sua capacidade de solução de problemas também foi avaliada usando a geração de problemas em várias dimensões e suas soluções.

Palavras-chave: Fatores humanos, aprendizado, esquecimento, fadiga, agendamento de pessoal

Introduction

One of the permanent challenges of middle managers is to provide proper scheduling to determine the staff shift. The significance of this issue becomes evident when proper scheduling leads to increased employee satisfaction and thus the provision of more desirable services and, ultimately, enhanced efficiency. Staff scheduling varies according to the nature of the unit under consideration. In recent years, scheduling concepts have been applied in issues such as sport tournaments, timetables of airlines and trains and also manpower scheduling. One of the most common issues in the scheduling of manpower is the scheduling of employee work shifts. Staff scheduling is the process of preparing the optimal and viable schedule for employees while considering the conditions of the organization, staff and working rules in order to meet the organization's job demand. Preparation of the best employee work schedule is often among the discrete and combinatorial optimization problems and requires an effective approach (Cai & Li, 2000). The first part of this process includes the determination of the number of employees with specific skills so that the demand for the required services is satisfied. The employees are assigned to the shifts in a way that the required levels of the staff are met at different times and in the following, tasks are assigned to employees for each shift. All workplace-related industrial regulations should be observed throughout the assignment process. It is hard to find good answers for this complicated problem with a lot of limitations and it is far more difficult to find an optimal answer which minimizes the cost and considers employee preferences. In many organizations, people who are involved in creating these time schedules need decision support tools in order to employ the right staff at the right time and at the right cost and at the same time achieve high levels of employee job satisfaction.

The development of mathematical models and algorithms for staff scheduling consists of the following parts: A) Demand modeling which includes the collection and use of historical data to predict the demand for services and their conversion to employee levels which are required for meeting service standards; B) considering available solutions for staff scheduling so that workplace regulations are satisfied in the best way and a wide range of goals, including employee demand coverage, cost minimization and maximized employee satisfaction, are achieved; C) an appropriate reporting tool so that it displays the solutions and provides the performance report (Ernst et al., 2004).

The importance of employee efficiency and satisfaction is one of the most crucial factors in workforce scheduling. Preparation of a desirable time schedule for optimal work of the staff, with respect to human factors, requires careful attention to employee characteristics such as satisfaction, health, fatigue, learning, forgetfulness, etc.

Classic scheduling theory is used for the workforce activity sequence problems and in the research background, usually human ergonomic features (such as fatigue, stress, etc.) and their impact on work shift scheduling problems have not been considered although human factors engineering research has shown that human has his own characteristics that distinguish him from other production factors. Dori et al. (2013) used human factors engineering principles in the scheduling theory in order to exploit the employees' optimal performance. An important feature of the proposed mathematical model is to consider the ergonomic dimensions of employees, including learning, forgetfulness and work-related fatigue. Fatigue includes a decrease in the individual's function over time in physical activities; it is not a homogeneous phenomenon and varies between completely physical and completely mental tiredness. Fatigue affects the performance of individuals and, consequently, their production rates (Akbari et al., 2012). Forgetfulness is another human factor that influences people's work. Usually, the lack of skill maintenance is interpreted as forgetfulness and results in reduced productivity and probably lower production quality. Nevertheless, measuring and modeling these factors are much more complex in planning and at the same time, by considering these factors, we can provide a time schedule which maximizes employee efficiency. On the other hand, attention to these issues will increase the flexibility of employees and thus the production system. Effective employee scheduling is one of the most important activities affecting the production system performance and it is vital to assign the right task to the right employee at the right time (Osman et al., 2012). Despite the importance of the issue, very little work has been done in the literature on the involvement of human factors in staff scheduling and plenty of work is still needed.

When formulating a mathematical programming problem that describes and illustrates the real situation of decision-making, the inherent uncertainties existing in the real-world or human complex systems, including human judgment fuzziness, should be reflected in the description of objective functions and constraints as well as display of parameters related to the formulated problems. To deal with uncertainty in decision-making, fuzzy programming models have been developed, which we intend to use in this study. The purpose of this research is to

present a mathematical model for employee scheduling in such a way as to minimize workforce costs and take into account employees' fatigue, learning and forgetfulness factors affecting their performance and increasing efficiency. Parameters of the proposed model encompass the fixed and variable costs of worker assignment, the individual's production rate at different times of work shift, the forgetfulness parameter (which indicates the degree to which a person forgets the skill in performing a task), the learning rate, the amount of time away from work and so on. The variables of the proposed model also suggest worker assignment to the work shifts. The objective function of the problem is to reduce workforce costs and increase efficiency. Research constraints should also consider the effect of learning and fatigue on the output rate of operators. Additionally, the manner of worker assignment to work stations and employee preferences are considered in limitations.

To illustrate the model efficiency, initially, low-dimensional problems are solved through precise methods, such as the branch and bound method, and then, a genetic algorithm is provided to solve high-dimensional problems.

Research literature

Staff scheduling is the process of creating time schedules for employees such that the organization can meet the demand for its goods and services. The first step in this process is to determine the number of employees with the specific skills required. Individuals are employed in work shifts in such a way that the required number of staff is met at different times. Then, in each work shift, the tasks are assigned to the employees. It is very difficult to find good answers to this complicated problem with a lot of limitations. It is more difficult to find the optimal answer so that the costs are minimized, employee preferences are considered, work shifts are distributed equitably and all restrictions related to labor laws and regulations are satisfied (Ernst & Jiang, 2004). In staff scheduling, in addition to meeting the demand for services, which may vary over a day and between days of a schedule, attempt is made to satisfy the employees' preferences since it is very likely that they feel discontented in case of the organization's little attention to employee preferences and overtime work due to insufficient number of staff (Topaloglu, 2012) while Brusco and Jacobs (2010) maintain that two critical challenges facing service organizations include finding ways to improve service productivity and create a balance between family and work responsibilities of their employees.

Staff scheduling has been considered by personnel managers and operational researchers in the last half century and occasionally, problems related to staffing, budgeting and short-term scheduling are also included in the scope of this issue. Although each of these domains has different time horizons, they have a great deal of dependency on each other.

Baker (2005) has divided workforce scheduling problems into three types: Work shift scheduling (or scheduling of the hours of the day); rest days scheduling (or weekdays scheduling) and tour scheduling. Tour scheduling is, indeed, a combination of the other two types of scheduling.

1- Work shift scheduling

Work shift scheduling refers to the problem of selection from a large potential accumulation of volunteers and the shifts in which they should work and also the assignment of the number of employees to each work shift in order to meet the demand, which is similar to the crew scheduling in transportation systems.

2- Rest days scheduling

Rest days scheduling includes determining how to spread out rest days between work days for different work lines. An important issue in the scheduling of rest days is to determine the work days for rest for each employee during the planning horizon of scheduling. Therefore, assignment of specific work shifts to the staff on work days is not considered here (Ernest, 2003).

3- Tour scheduling

Many organizations face the staff scheduling problem under the conditions that service demand varies during operational days and throughout the scheduling horizon. These organizations are faced with the tour scheduling problem which embraces the assignment of work shifts and rest periods to staff's work days and also assignment of rest days to people's work schedules (Topaloglu, 2012).

The tour scheduling combines the two methods of work shift scheduling and rest days scheduling. This process involves both selecting rest days for employees and assigning work

shifts to any of their working days within the scope of the planning horizon. When the planning horizon is one day, the tour scheduling will be reduced to work shift scheduling and when there is only one work shift every day, it reduces to the rest days scheduling.

Despite the fact that this type of schedules is created simply and covers the need for the staff, they are not flexible at the time of responding to individual preferences or minor changes in the personnel's demands (Admint, 2010). Cyclic staff scheduling is a common method for solving the staff scheduling problem. In this method, first, all possible working patterns, usually on a weekly basis, are created while considering various work restrictions, such as the length of work intervals, weekend rest and lack of separate rest and work days. Moreover, only those patterns are allowed that can be part of a larger schedule. For example, if base patterns are weekly, then certain patterns cannot be combined because of the limitations related to work intervals. The reason for the naming of cyclic scheduling is that nurses are moving between all patterns. The study conducted by Ahuja and Sheppard (1997) is a practical application of the cyclic staff scheduling. The nature of this approach is such that it considers all employees equally and in this way, employee preferences cannot be taken into account. In the best state, employees can choose their own desired pattern from a set of optimal cyclic patterns. Thus, this approach cannot be used in cases where employee preferences are important. Although cyclic scheduling is usually regarded as the scheduling that can be performed more simply, most of them have been created by traditional innovative techniques.

Megeath (1998) describes a simple way to create cyclic work schedules for nurses with three levels of skill in a six-week interval. He presents a seven-day cyclic pattern of work shifts and rest days, which provides the possibility of the balanced coverage of work shifts. Ahuja and Sheppard (1997) developed a cyclic scheduling program in which an active computer terminal is used that helps the decision-maker select the working patterns in such a way as to provide the required coverage for nurses with specific skill levels in each work shift. Mayer Rothe Woolf (1997) created a model for cyclic staff scheduling which satisfies the needs of different sections of an organization by using employees' floating accumulation. In this model, the additional staff required is determined on the basis of daily measurement of people's needs and skills of employees who are assigned to the tasks in the cyclic scheduling program. An integer programming algorithm with three steps was prepared for cyclic staff scheduling, whose aim is to minimize the number of additional employees in addition to demand coverage.

Hung (1999) provided a permanent shift system for the cyclic scheduling of nurses in 10-hour shifts and in 4-day working weeks. People who work at one time make up a team. This system provides the possibility that by considering coverage constraints and some time-related limitations, people at lower skill levels are replaced in order to make up the deficiencies in higher skill levels. In another article, Hung examines the working week rearrangement, permanent work shifts, phased sequential delay, shift overlap and self-scheduling. He identifies some of the motivational benefits of self-scheduling, including a more effective work schedule resulting from the fact that employees know that their individual preferences are considered and thus become more interested in cooperation and partnership.

Unlike the cyclic scheduling in which each employee works in a pattern repeated in successive scheduling intervals, in the non-cyclic scheduling, a new schedule is created for each time of scheduling. In a non-cyclic scheduling program, the work path of each employee is completely independent. This situation is used in cases where demand varies with time and the work shifts have different lengths and starting times (Ernest, 2004). That is why the cyclic scheduling is also called fixed scheduling and non-cyclic scheduling is also referred to as flexible scheduling (Silvestro, 2006). Non-cyclic models have attracted greater attention than cyclic models.

It is very difficult to optimally solve the tour scheduling problem due to the large size and the nature of pure integer. In recent decades, numerous approaches have been proposed to model and solve this problem. This type of scheduling problem is a practical problem for organizations like hotels, airline companies and hospitals that work seven days a week and have more than one work shift each day. Undoubtedly, employees should be given daily and weekly rests. Therefore, they should be assigned specific rest days during each week and specific rest hours during each day. In other words, it is necessary to define special tours based on which each employee should work. Accordingly, in this problem, the aim is to determine the number of people employed in each work tour to meet the work demand for each working hour per day at a minimum cost or with a minimum labor force (Hesham, 2008).

In this regard, Akbari (2017), in an article, has investigated the temporary labor scheduling problem with variable performance. Comparison of results revealed that the genetic algorithm has desirable performance in finding satisfactory answers in the appropriate computational time. This research demonstrated that staff fatigue can be modeled in employee

scheduling and planning and in order to reduce staff costs and increase production efficiency, flexible work shifts can be considered. In this regard, fatigue is a decrease in individual function over time in physical activities (Guastello, 2006).

Besides, Dori et al. (2013) investigated the effect of learning and fatigue on staff scheduling and job rotation and used exponential and power functions. In this study, the individual's efficiency during the work shift is calculated using the learning-forgetting function and then, this amount of efficiency is corrected by taking into account the reduction in the individual's efficiency as a result of fatigue.

Fatigue is not a homogeneous phenomenon and varies in the range of completely physical and completely mental tiredness. Fatigue affects the performance of individuals and, consequently, their rate of production (Niebel, 1962) and also makes a negative impact on staff health. Although fatigue cannot be eliminated, it can be reduced by proper planning (Guastello, 2006). Therefore, it seems essential to consider staff fatigue in scheduling and production planning.

By the same token, important learning models were examined in the study by Nembhard (2000) while considering the three measures of efficiency, sustainability and saving (number of model parameters) and using real data. Further, in their article, Yan and Wang (2011) attempted to simultaneously model the effect of learning and forgetfulness on workforce efficiency in the workforce scheduling problem. In 2011, Easton engaged in multi-tasking staff modeling in the flexible environment of employee scheduling with regard to staff costs and service level. This researcher came to the conclusion that in most cases, the performance of multi-tasking staff is better than expert staff. In staff scheduling, it can be mentioned that only the factors of learning and forgetfulness have been objectively considered. In another article, Akbari (2017a) has studied and modeled important human factors in the staff scheduling problem by applying human factors engineering in dual constraint systems. Dual constraint systems are the systems in which production capacity constraints arise from two human and machine factors.

Considering that this research is of an optimization type, statistical tests and hypotheses are not applicable in this study. The most important questions of this research are as follows:

1- How is the mathematical model structure for the staff scheduling problem with regard to human factors?

2- Is genetic algorithm effective to solve the staff scheduling mathematical model?

3- What is the impact of human factors on the model output?

The research hypotheses are as the following:

1- The cost of worker assignment, including fixed and variable costs, is based on the amount.

2- Working lines include workstations and each workstation requires a special skill. The employees are skilled in doing the works related to all workstations.

Research methodology

This study is an applied research in terms of purpose and a descriptive survey research in terms of data collection method. To increase employee efficiency, parameters related to fatigue and forgetfulness are considered in the staff scheduling mathematical model and the proposed model is solved by standard methods. After the mathematical model was solved and its accuracy was shown on low-dimensional problems, given that the staff scheduling model is one of the NP-Hard problems (Belazovich et al., 1983) and with increasing the number of employees, the number of work shifts or the number of workstations, the duration of the implementation of exact methods increases exponentially, a genetic algorithm was proposed to solve a high-dimensional problem in the next step. For the proposed genetic algorithm, one should specify how to display the answer and crossover operator and effective mutation should be provided so that optimal or near optimal answers can be achieved within a reasonable time. High-dimensional problems were solved using the proposed genetic algorithm and the genetic algorithm efficiency was shown. In this research, MATLAB software was employed to solve high-dimensional problems.

Research findings

Validation of the proposed model

In order to validate the proposed model, a low-dimensional problem has been designed and solved by GAMS software. To this end, the inputs related to the designed example are reported. Table (1) displays the values of some of the parameters.

Table 1: Values of some of the parameters

Parameter	Value
fc	100,000
vc	25,000
ac	10,000
wc_{max}	0.9
wc_{min}	0.4
a_{max}	12
r	50
β	0.05

Table (2) shows the duration of each work shift and the amount of production required per shift

Table 2: Duration and the amount of production per shift

Parameter	Work shift	Work day		
		1	2	3
Duration	1	3	3	3
	2	3	3	3
Required amount of production	1	50	50	50
	2	50	50	50

The above problem has been solved by GAMS software on a dual-core system with a 3GHz CPU and 2GB RAM within about one second and its outputs have been reported in the table below. Table (3) shows that to which shift and station each worker has been assigned in each day.

Table 3: Workforce assignment

Worker	Work day	1	2	3

	Station Shift									
1	1									
	2									
2	1									
	2									
3	1									
	2									

The values of the objective function obtained from solving the above problem are presented in Table (4).

Table 4: Values of the objective function

Objective function	Value
Workforce costs	5,712,867
Profits from the efficiency of individuals	361,697
Total	5,351,170

As mentioned, in the following, several low-, medium- and high-dimensional problems have been designed and solved by GAMS software. The generation of the sample problem has been described in tables (5) and (6).

Table 5: Generation of the main indexes of the problem

Dimensions of the problem	Problem number	Number of employees	Number of work shifts	Number of workstations	Number of working days
Low	1	3	2	3	3

	2	4	2	4	4
	3	5	2	5	5
Medium	4	10	3	6	5
	5	12	3	8	6
	6	15	3	10	6
High	7	20	3	12	6
	8	25	3	14	7
	9	30	3	16	7

Table 6: Values of other parameters

Parameter	Value
Fc	100,000-200,000
vc	25,000-50,000
ac	10,000-20,000
wc$_{max}$	0.9-0.95
wc$_{min}$	0.4-0.45
a$_{max}$	12-15
r	50-200
β	0.05-0.1

As can be observed in Table (7), three low-dimensional problems, three medium-dimensional problems and three high-dimensional problems have been generated. It should be noted that the outputs obtained from solving each sample problem are shown in Table (7).

Table 7: Answer obtained from GAMS software

Dimensions of the problem	Problem number	First objective function	Second objective function	Total
Low	1	5,712,867	361,697	5,351,170

	2	6,011,142	398,452	5,612,690
	3	6,214,203	415,624	5,798,579
Medium	4	7,214,097	731,415	6,482,682
	5	8,341,124	801,429	7,539,695
	6	-	-	-
High	7	-	-	-
	8	-	-	-
	9	-	-	-

As provided in Table (7), GAMS software has had the ability to fully solve the low-dimensional problems. Also, it could solve some of the medium-dimensional problems but was not able to solve high-dimensional problems. Further, it is observed that with increased number of employees and workstations, workforce costs and also the profit generated by efficiency have increased. Figure (1) shows the process of changes in the objective functions for various problems solved.
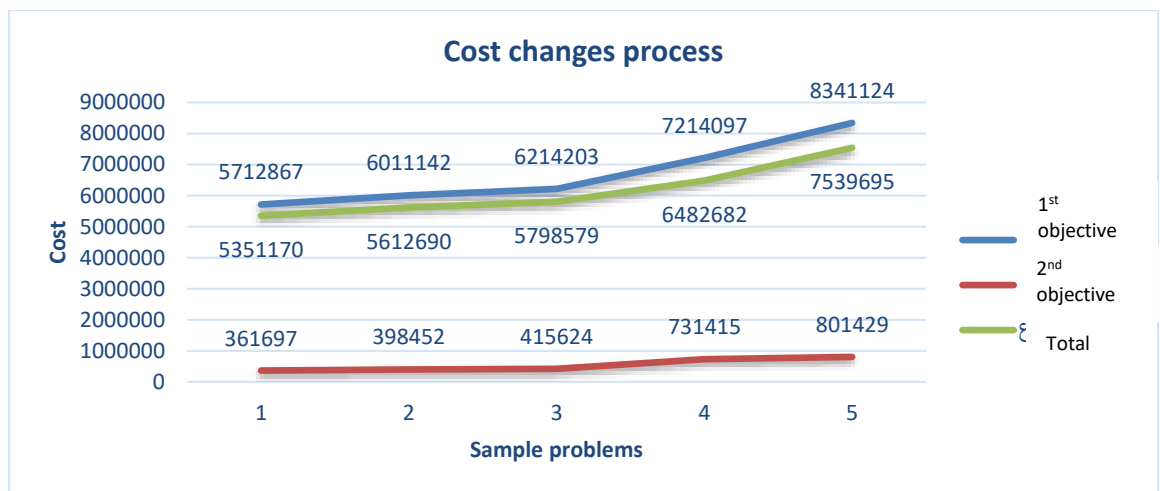

Figure 1: Process of changes in the cost for various problems solved by GAMS software

As shown in Table (7), GAMS software has not been able to solve high-dimensional and some of the medium-dimensional problems. Thus, to solve this category of problems, a metaheuristic genetic algorithm has been developed.

Solving high-dimensional problems by the genetic algorithm

As stated, to solve the manpower scheduling problem in different work stations by considering the work shift and with the aim of time minimization of the total costs, a metaheuristic genetic algorithm has been developed. According to the explanations presented about the genetic algorithm in the third section, the input parameters of the algorithm have been initialized as follows:

Initial population 50

Number of iterations 100

Crossover operator rate 0.7

Mutation operator rate 0.3

As mentioned, in order to assess the accuracy of the proposed genetic algorithm, low- and medium-dimensional problems solved by GAMS software are re-solved by the proposed genetic algorithm, and its outputs are reported. Also, high-dimensional problems are solved by the proposed genetic algorithm and the results have been reported in Table (8).

Table 8: Solution of sample problems by the proposed genetic algorithm

Dimensions of the problem	Problem number	Solved by the proposed GA			Solved by GAMS Software	Difference percentage
		First objective function	Second objective function	Total	Total	
Low	1	5,712,867	361,697	5,351,169	5,351,169	0
	2	6,011,142	398,452	5,612,690	5,612,690	0
	3	6,214,203	415,624	5,798,579	5,798,579	0
Medium	4	7,214,097	731,415	6,482,682	6,482,682	0
	5	8,352,422	804,318	7,548,104	7,539,695	0.1
	6	9,634,420	876,248	8,758,172	-	-
High	7	12,457,201	1,547,321	10,909,880	-	-
	8	14,861,014	2,087,452	12,773,562	-	-
	9	17,213,408	3,167,158	14,046,250	-	-

As can be seen in Table (8), the genetic algorithm has had the ability to solve all the sample problems. Based on the comparison of the results obtained from two methods for solving low- and medium-dimensional problems, it can be found that the genetic algorithm has had sufficient accuracy to achieve the optimal answer since the difference percentage of the objective functions obtained from the two methods in solving low-dimensional problems is zero, meaning that the genetic algorithm has had the ability to achieve the optimal answer.

Figure (2) shows the process of changes in the objective function for sample problems for the proposed genetic algorithm. As can be observed, the larger the dimension of the problem, the greater the costs will be.
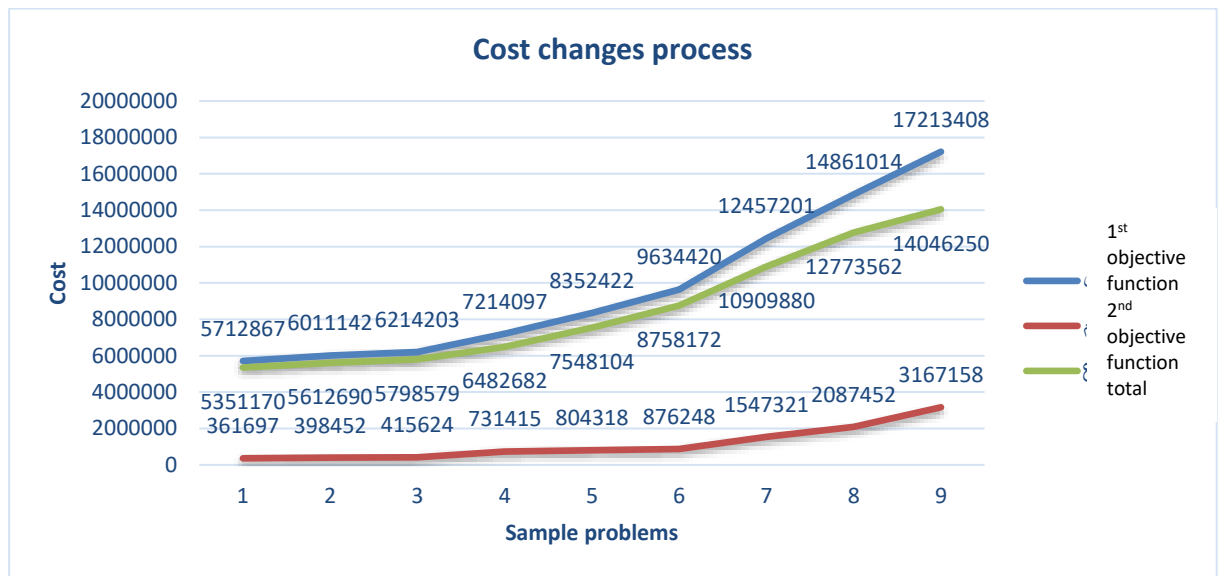
Figure 2: Process of changes in the cost for different sample problems solved by the proposed genetic algorithm

In the following, as stated earlier, a comparison has been made between the results obtained from the two methods for solving low- and medium-dimensional problems. According to Table (9), it can be seen that the first three problems, which are among low-dimensional problems, are solved by both methods and exactly the same answer has been obtained. The two medium-dimensional problems have been solved by both methods, in one of which the same answer has been achieved and in another, a very slight difference can be observed. The obtained results indicate the acceptable performance of the proposed genetic algorithm. Moreover, Figure (3) displays the process of changes in the value of the objective function relative to the number of iterations. As can be seen, with increased number of iterations, the total cost has decreased. This trend also suggests the accuracy of the proposed algorithm.
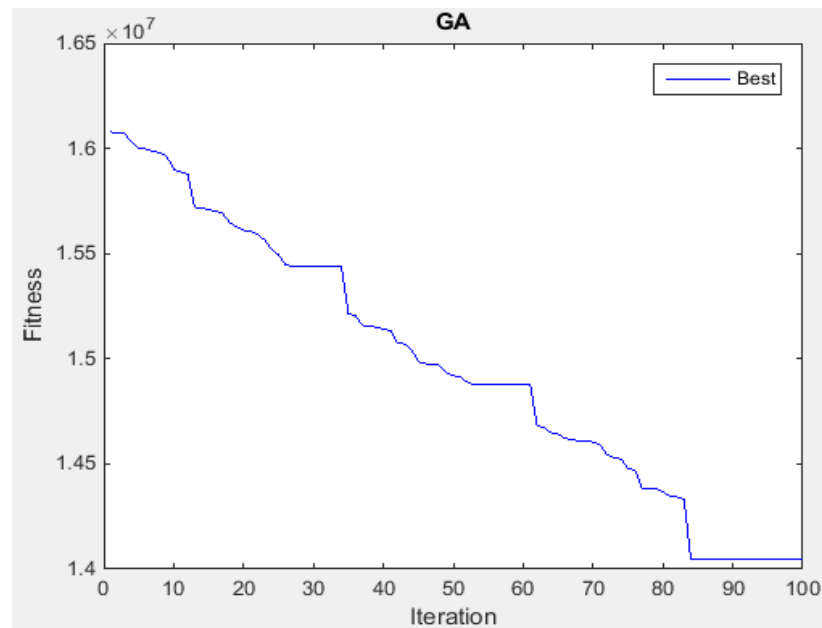
Figure 3: Process of changes in the objective function relative to the number of iterations

The limitation of this research is related to the specific limitations of the questionnaire resulting from the biases displayed by some members in answering some of the questions, which is among the major limitations of scientific research. Further, the novelty of the subject and the lack of similar studies that have quantitatively analyzed the research hypotheses made it difficult to compare the quantitative results with other studies. The restriction of access to the scientific articles of the day due to sanctions and the inability to purchase some of the new articles is another limitation of this research.

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