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Research Article

Human Resource Scheduling in Project Management Using the Simulated Annealing Algorithm with the Human Factors Engineering Approach

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Manpower scheduling means assigning a work pattern (shift day) according to the wants and needs of the system and the workforce with the goal of minimum cost. Many production and service systems require multiple scheduling. This problem is generally NP-complete, and it takes a long time to solve it through the current method. Today, several innovative methods have been proposed to solve such problems. In this paper, the simulated annealing method (SA) has been used. The problem in this study is in an oil extraction project for human resource scheduling, which consists of three human resource groups in four task types in oil exploration operations, including geology, geophysics, petrophysics, and oil engineering. To solve the human resource scheduling problem, a meta-heuristic algorithm called simulated annealing algorithm was applied, and the result indicated that the allocated human resource was scheduled with the least fatigue implementing the proper job rotation.

1. Introduction

Preparing a favorable timetable for work shifts and workflow of employees with the approach of human factors engineering requires careful attention to the characteristics of employees such as satisfaction, health, stress, motivation, and so on. To increase employee satisfaction and health, using job rotation schedule and multiskill staff is a very appropriate method. But the costs of relocation increase the costs of the organization [1].

Naft-e-Khazar Company was established in January 1998 as one of the subsidiaries of the National Iranian Oil Company. The company is responsible for the exploration, development, and production of hydrocarbon resources in the South Caspian Basin and the three coastal provinces of Mazandaran, Golestan, and Gilan. Monitoring the implementation of all contracts concluded between the National Iranian Oil Company and international companies for the study and development of oil fields in the Caspian Sea, as well as monitoring environmental issues associated with the exploration and development of oil and gas reserves in the Caspian Sea are the responsibilities of the Naft-e-Khazar Company. The geology consists of three sections: geological studies, operations, and laboratories. The studies section is the basis of any exploration operation, and its study technical output is provided to other departments of the geological survey. Geophysics includes departments for monitoring the operation of geophysical data, monitoring the processing of geophysical data, geophysical data interpretation, and management system department. Seismic surveys, data processing, and interpretation, as well as the study and design of seismic lines, are among the geophysics department's activities. The aim of petrophysics is to identify underground hydrocarbon reservoirs and evaluate the rock and fluid properties of the reservoir, and its output is the static and dynamic description of the reservoir and how the fluid is distributed in the well and beyond. However, the job rotation advantage in enhancing performance has not been confirmed with certainty. The use of very simple and nonheuristic rules, such as allocating different tasks relative to what has been done by the operator in the past period, does not lead to performance enhancement, and it is necessary to develop models based on heuristic rules in a way that performance enhancement is achieved by modifying how tasks are scheduled [2, 3].

The main objective of the paper is to develop a plan for the problem of job rotation scheduling to overcome workers' double fatigue. For this purpose, the main question of the paper is how to develop a plan for the problem of job rotation scheduling to overcome the double fatigue of workers. Therefore, the main contribution of the paper is as follows:

(i) A nonlinear integer model is proposed for the job rotation scheduling problem
(ii) A new idea is suggested for calculating the fatigue cost of each operator by introducing positive and negative fatigue due to the similarity of tasks allocated to each operator
(iii) The proposed model can calculate allocation costs; the fatigue cost could be included in job rotation scheduling; and decision efficiency could be developed
(iv) Simulated annealing meta-heuristic search algorithms will also be implemented to solve the model

The rest of paper is organized as follows: Section 2 presents a literature review. Section 3 presents research methodology. Section 4 presents results and unique research finding. Section 5 presents managerial insights and practical implications, and finally, Section 6 presents conclusion and suggestions for further research.

2. Literature Review

The model of the workforce scheduling program in service and production systems is considered by creating a work pattern for each staff [4]. Application and job rotation encompass a wide range of manufacturing companies; a variety of tasks; advanced industrial systems, such as cellular manufacturing industries; and service organizations, such as hospitals, police departments, fire departments, bus companies, and so on [5]. However, research on the impacts of employing job rotation has yielded contradictory results in practice in which its advantage in improving employee performance cannot be considered conclusively proven [3]. In this regard, Bhadury and Rdovilsky [6] have presented three multiperiod and two-objective allocation models and some simple heuristic methods to obtain the desired justified answers and claim that these three models are more effective than previous models and are closer to reality. Huang et al. [7] categorized the constraints to solve the problem with a large number of nurses, longer planning time, and many constraints using an evolutionary algorithm. According to him, the more nurses and the time we plan for it, the more complex the problem becomes. Avadí et al. [8] modeled the problem definitively and solved it using a hybrid algorithm. This solution method combines two evolutionary meta-heuristic algorithms and local search to improve the generated solutions. Santos et al., using the concept of integer programming, solved the problem in an innovative way. In this study, the absence of nurses has been proposed as an effective factor in the schedule. Hochdörffer et al. [4] in their study planned a short-term employee scheduling system. Demographic change is a well-known influencing factor challenging social security systems in industrialized countries. In a manufacturing context, companies need to cope with an increasingly heterogeneous workforce in terms of qualification and impairments, as well as increasing average age. The improvement of more standardized processes and the trend to move towards shorter lead times, paired with demographic changes in the workforce reveal strong importance of staff planning. A short-term staff planning system, which generates job rotation schedules taking into consideration workers' qualifications, the workplace's ergonomic exposure, and the most recent allocations of each worker, is sought to ensure the right worker is allocated to the right workplace at the right time. The arising complexity of such scheduling problems is met in this study by implementing a linear programming-based heuristic, which solves the scheduling problem gradually for each rotation around and generates a holistic job rotation schedule for an entire workday. The presented approach to short-term staff scheduling is used in a VBA-based software prototype and was tested in the final assembly line of a German automotive manufacturer. Ayough et al. [9] in their study investigated the performance of human resources with respect to forgetting, boredom, and learning. The performance of a manufacturing cell depends on an efficient layout design and optimal work schedules. However, the operator-dependent factors such as learning, forgetting, motivation, and boredom can considerably impact the system output. In this study, we consider heterogeneous operators with dynamic performance metrics and integrate the job assignment and job rotation scheduling problems with the balancing and production sequencing in a U-shaped lean manufacturing cell. A novel multiperiod nonlinear mixed-integer model is presented to minimize the deviations from tact time and the number of operators in a finite planning horizon. An efficient meta-heuristic approach is developed to solve the problem, and the results are compared to a static case where no human factor is included. The computational results demonstrate that including the operator-dependent metrics could develop the cell design performance. Lotfi et al. [10] recommended using blockchain technology (BCT) for growing faster in each country. They believe it is essential to apply BCT in supply chain network design (SCND) and is considered by the designer and manager of a supply chain. For this, Lotfi et al. [11] presented a survey applicable blockchain technology (BCT) in project management for the first time. For this purpose, a resource-constrained time-cost-quality-energy-environment tradeoff problem is presented by considering BCT, risk, and robustness (RCTCQEETPBCTRR) in project scheduling. The proposed framework utilizes hybrid robust stochastic programming, worst case, and conditional value at risk (CVaR) to cope with uncertainty and risks.

2.1. Research Gap. Previous studies have focused on analyzing and prioritizing key human resources in organizations. Therefore, it is necessary to propose a new idea to calculate the cost of fatigue of each operator by introducing positive and negative fatigue due to the similarity of the tasks assigned to each operator. For this purpose, a nonlinear integer model for the work rotation scheduling problem is proposed in this research; the proposed model can calculate the allocation costs; the fatigue cost can be included in the job rotation planning; and the decision efficiency can be developed. Finally, the implementation of simulated meta-heuristic search algorithms will also be implemented to solve the model.

3. Research Methodology

Scientific research is divided into three categories based on the purpose of research: applied, and research and development. In this classification, the present study is in the group of applied research. The purpose of applied research is to develop applied knowledge in a specific field. In other words, applied research leads to the practical application of knowledge. In fact, applied research is research that uses the cognitive context and information provided by basic research to meet human needs. To formulate the theoretical framework of the research, previous researches have been studied and evaluated and the theories, concepts, and variables are developed based on them. The solution method used in this research is a meta-heuristic algorithm.

3.1. Model Assumptions. The main assumptions of the paper are as follows:

(i) There is no time limit for doing the set of tasks in each planning period
(ii) There is no time limit for the availability of each operator in each planning period
(iii) The allocation of similar tasks is evaluated as favorable in each planning period and as unfavorable in several planning periods
(iv) All parameters and problem data are definite and constant in each planning period

3.2. Definitions and Symbols of the Model. If the number of planning periods (without losing the generality of each period from now on is considered a working day) is equal to K, the counting indices of the parameters and variables of the problem decision and the parameters are symbolized as follows.

3.2.1. Indices

i: operator $(i = 1, 2, \ldots, I)$
j: task $(j = 1, 2, \ldots, J)$
K: day $(K = 1, 2, \ldots, k)$

3.2.2. Parameters

C_{ij}^{k}: cost of doing task j by operator i on day k.

$p_{j' j}$: the amount or degree of similarity of the two tasks j and j' .

DOR: the number of days during which the degree of similarity of the tasks allocated to each operator is calculated. That is, if the goal is to calculate the degree of similarity of the tasks allocated to operator i to day k, days $K - \text{DOR} + 1$ to K need to be considered. Obviously, the DOR is smaller than K.

a_1: cost of daily fatigue of operator i felt as a result of the allocation of tasks throughout the planning period.

3.2.3. Decision Variables

x_{ij}^{k}: if task j is allocated to operator i on day k, it will be equal to one. Otherwise, it will be equal to zero.

z_1: if the total operator fatigue value is negative, it is zero. Otherwise, it is one.

The following are definitions that lead to the calculation of the cost of fatigue due to the allocation of similar tasks during planning periods to each operator.

3.2.4. Positive Fatigue. For each operator on each day, $B(i, k)$ is created due to the similarity of the tasks allocated to the operator on that day. If the operator is allocated only one job on a particular day, the favorable fatigue for the operator is equal to 1.

$$\forall k = 1, 2, \ldots, k; \forall i = 1, 2, \ldots I, \tag{1}$$

$$B^{+}(i, k) = \sum_{j=1}^{j-1} \sum_{u=1}^{J-j} x_{ij}^{k} \cdot x_{ij+u}^{k} + P_{jj+u}. \tag{2}$$

3.2.5. Negative (Unfavorable) Fatigue. For each operator on each day, $B^{-}(i, k)$ is calculated based on the similarity of the assigned tasks from the kth day to the DOR-1 day before.

$$\forall k = 1, 2, \ldots, k; \quad \forall i = 1, 2, \ldots I,$$

$$B^{+}(i, k) = \sum_{t=1}^{\text{Min}\{k-1,\text{DAYS-OFF-ROTIN}-1\}} \sum_{j=1}^{j-1} \sum_{u=0}^{J-j} x_{ij}^{k} \cdot x_{ij+u}^{k} + P_{jj+u}. \tag{3}$$

3.2.6. Total Fatigue of Operator (i) BORNING. It is the fatigue that the operator feels during the planning period and is equal to the difference in the share of each day of maximum fatigue due to the similarity of the allocated tasks on DOR consecutive days and the minimum favorable fatigue for allocating similar tasks.

$$\forall k = 1,2,\ldots,k; \forall i = 1,2,\ldots I,$$

$$\text{BORNING}(i) = \frac{\text{Max}_k\{B^-(i,k)\}}{\text{DOR}}\text{MIN}_k\{B^+(i,k)\} \longrightarrow \text{BORNING}(i) = \frac{B^-(i)}{\text{DOR}}B^+(i). \tag{4}$$

There will be no cost if the total operator fatigue value is negative.

3.3. The Proposed Model. The objective function in this model (equation (5)) consists of two expressions: the first is the total cost of the task performed by each allocation and the second is the sum of the fatigue cost of each operator due to the feeling of fatigue because of the allocation of similar tasks over the planning horizon, which is formulated nonlinearly.

$$\text{Min } Z = \sum_{t=1}^{i}\sum_{j=1}^{j}\sum_{k=1}^{k} c_{\text{ij}}^{k}\cdot x_{\text{ij}+u}^{k} + z_i \sum_{i}^{i} \text{BORINIG}(i), \tag{5}$$

$$\sum_{i=1}^{I} x_{\text{ij}}^{k} = 1 \quad \forall k = 1,2,\ldots,k; \forall i = 1,2,\ldots I, \tag{6}$$

$$\sum_{j=1}^{J} x_{\text{ij}}^{k} = 1 \quad \forall k = 1,2,\ldots,k; \forall i = 1,2,\ldots I, \tag{7}$$

$$x_{\text{ij}}^{k} = 0,1, \tag{8}$$

$$z_i = 0,1, \tag{9}$$

$$(I - z_i)M + \text{BORNING}(i) \geq 0 \quad \forall i = 1,2,\ldots,k, \tag{10}$$

$$-z, M + \text{BORNING}(i) \leq 0 \quad \forall i = 1,2,\ldots,k. \tag{11}$$

Equation (7) based on assumption (2) and inequality (8) and of equations (9) and (10) expresses the model being an integer (of type zero and one). Inequalities (10) and (11) make the constraint of the operator fatigue being positive operational to calculate the associated cost.

3.4. Algorithm Design. Simulated annealing is a random search technique for global optimization problems in which the process of producing solid crystals from molten material is modeled by cooling the melt. The slower the rate of temperature decrease in the molten material, the slower and more orderly the solid crystals are formed. As a result, the resulting solid will have less porosity, and the solid crystal will be in a better position in terms of impact resistance. Therefore, the annealing process involves precise control of temperature and cooling rate. It can also be stated that the performance of the simulated annealing algorithm equals dropping a few rolling balls on an uneven surface. As the balls bounce back and forth and lose energy, they eventually focus on some local minima. If the balls are allowed to jump around enough, that is, to lose enough energy and slowly, some of the balls will eventually fall into the lowest global place (global minimum). Therefore, the global minimum will be obtained. The simulated annealing algorithm is as follows:

(1) Define the objective function and adjust the algorithm parameters

Define initial temperature T and initial value $x^{(0)}$

Define final temperature T and number of iterations N

Define the temperature decrease rate α

(2) Until $(\mathbf{n} < \mathbf{N}, \mathbf{T} > \mathbf{T_F})$

Randomly move to a new location (make changes to the current answer for random search): $x_{n+1} = x_n +$ rand

Calculate $\Delta f = f_{n+1}(x_{n+1}) - f_n(x_n)$

(3) If the new answer is better, it will be accepted

Otherwise, a random number r is generated

If $p = \exp[-\Delta f/T] > 7$, the new answer will be accepted

Finish the loop

Update $x^* f^*$

$N = n + 1$

Finish the loop

3.5. Adjusting the Initial Parameters. First, we specify the parameters of the SA algorithm, which are checked based on parameter adjustment and trial and error, and these numbers are obtained, which are as follows:

Number of populations = 20

Popsize = 20

Number of iterations = 100

Maxiter = 100

Initial temperature = 100

$T0 = 100$

Final temperature = 1

$T_f = 1$

Cooling diagram = linear

$T_{\text{damp}} = ((T_0 - T_f)/\text{maxiter})$

Number of neighbors = 5

$N_n = 5$

4. Results

As it can be seen in Figure 1, iteration fatigue has a constant value of 20, and it can be concluded that the fatigue cost is optimized after this iteration.

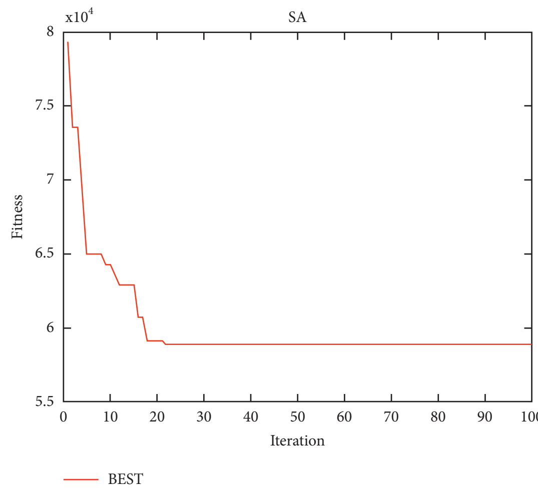

Figure 1: Performance of the simulated annealing algorithm for human resource scheduling.

Table 1: Number of working days.

i	j	k_1	k_2	k_3	k_4	k_5
1	1	0	0	0	1	0
1	2	0	1	0	0	1
1	3	1	0	1	1	0
1	4	0	0	0	0	1
2	1	0	0	0	0	1
2	2	0	0	1	0	0
2	3	0	1	0	0	0
2	4	1	1	0	1	0
3	1	1	1	1	0	0
3	2	0	0	0	1	0
3	3	0	0	0	0	1
3	4	0	0	1	0	0

Table 2: Results of the research.

Problem number	K, number of days	J, number of tasks	I, number of operators	DOR, degree of similarity of tasks	Best fitness objective (meta-heuristic	Optimal objective (mathematical)	ARE	Time
1	3	3	2	2	50,828	50,000	0.01	6.365
2	5	3	2	2	72,600.71	72,000	0.001	6.986
3	5	3	2	3	65,269.49	60,000	0.08	6.709
4	5	5	3	2	86,052.21	86,000	0.006	11.899
5	5	5	3	3	73,216.44	73,000	0.002	11.897

Now, we consider the final answer that i represents the number of operators and j represents the number of tasks, including geology, geophysics, petrophysics, and petroleum engineering tasks, and k represents the number of working days in Table 1.

According to the results of solving the model, it can be concluded that operator 1 does task 1 on day 4 and operator 1 does task 2 on day 2, and thus, the best human resource schedule was obtained with the least fatigue.

Efficiency meta-heuristic algorithms were also proposed to overcome the algorithmic complexity of the job rotation scheduling problem, and the quality of the SA algorithm was confirmed in this problem, which could encourage other researchers to use this algorithm at least to solve multiperiod allocation models with diverse applications. Since the proposed model creates new and flexible concepts for designing the job rotation scheduling problem, redefining and scrutinizing the concept of similarity of two tasks and costs due to fatigue and so on could add more and more real applications to the model. For this purpose, absolute relative error (ARE) $\text{mathematicalmodel} - \text{metahuristic}/\text{metaheuristic}$ has been used to accept the mathematical model. ARE has been recommended by Mahmoudi et al. [12]. When, between mathematical model output and meta-heuristic model, ARE is lower than 0.05, it means that the mathematical model can predict the behavior real system. Also, the results of the validation are shown in Table 2.

The results of investigating the model in problems with larger dimensions in the above-mentioned table show that by comparing rows 1 and 2, we conclude that with increasing days, the time to achieve the best objective function increases. By comparing rows 2 and 3, we conclude that with increasing DOR, that is, the number of days during which the degree of similarity of the tasks allocated to each operator is calculated, the time to achieve the best objective function decreases. By comparing rows 4 and 5, we conclude that with increasing DOR, that is, the number of days during which the degree of similarity of tasks allocated to each operator is calculated, the time to achieve the best objective function decreases. Also, the ARE value in the execution of all problems is calculated at less than 0.05 by comparing the two values of the objective function in the mathematical and meta-heuristic model. Therefore, it can be concluded that the meta-method will be able to solve problems on a large scale.

5. Managerial Insights and Practical Implications

According to the main advantages of the paper, it can be concluded that in the process of oil exploration management, in this paper, four tasks of geology, geophysics, petrophysics, and oil engineering were investigated, and it was concluded that the more similar the four tasks of exploration are, the higher the cost of human resource fatigue. Therefore, Naft-e-Khazar Company should avoid the employment of people in similar tasks in allocating its human resource to these four exploration tasks, and given that these four tasks are very similar in many sections, it should use job rotation among other tasks to prevent human resource fatigue and burnout.

6. Conclusion

In this study, a new and flexible model was provided that can be used to revolutionize scheduling tasks allocated to each operator during planning periods (called the job rotation scheduling problem) compared to other models. For this purpose, the paper develops a plan for the problem of job rotation scheduling to overcome workers' double fatigue. Therefore, this paper presents a nonlinear integer model that is proposed for the job rotation scheduling problem. It also suggests a new idea for calculating the fatigue cost of each operator by introducing positive and negative fatigue due to the similarity of tasks allocated to each operator. Results show that proposed model can calculate allocation costs, the fatigue cost could be included in job rotation scheduling, and decision efficiency could be developed. Finally, implemented simulated annealing meta-heuristic search algorithms to solve the problem, because the comparison of the mathematical model and the meta-heuristic model shows that the meta-heuristic model will be able to predict the behavior of the model in the long term. This research has a valuable contribution to achieving the management goals of the Naft-e-Khazar Company. Therefore, Naft-e-Khazar Company should avoid the employment of people in similar tasks in allocating its human resource to these four exploration tasks, and given that these four tasks are very similar in many sections, it should use job rotation among other tasks to prevent human resource fatigue and burnout. The main advantages of the research are as follows [9, 13–18]:

(i) A nonlinear integer model is proposed for the job rotation scheduling problem

(ii) A new idea is suggested for calculating the fatigue cost of each operator by introducing positive and negative fatigue due to the similarity of tasks allocated to each operator

(iii) The proposed model can calculate allocation costs; the fatigue cost could be included in job rotation scheduling; and decision efficiency could be developed

(iv) Simulated annealing meta-heuristic search algorithms will also be implemented to solve the model

Finally, a suggestion for further research is the development of the model taking into account uncertain parameters because, in the real world, systems are always faced with uncertainty.

Data Availability

The data used and the pseudocodes are included in the article. Codes are available upon reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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