

Solving a Real Case of Seafaring Staff Scheduling Problem Using Cuckoo Optimization Algorithm

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ABSTRACT

This work deals with human resource scheduling problem (HRSP) where fairness is a very important factor when assigning different shifts to the seafaring teams. This type of problem is part and partial of the NP-hard problems category. The authors propounded to work out this seafaring staff scheduling problem (SSSP) using one of the population-based meta-heuristics called cuckoo optimization algorithm (COA), one of the newest, most robust, and most popular bio-inspired algorithms. rnAffording schedules that ensure an enhanced staff rest to the company compared to the traditionally used ones was the main objective of the paper. The results indicate that this method outperforms the traditional one in solving this NP-hard problem. In addition, they prove the COA performance in the improvement of the objective function value compared to the previously proposed methods in the literature, namely GRASP and ABC. Finally, the use of the COA in scheduling also increased the total posts to be assigned by one compared to the ABC method.

KEYWORDS

Cuckoo Optimization Algorithm, Scheduling, Seafaring Staff

1. INTRODUCTION

Staff management is considered one of the most important issues in the logistics activity. Despite the fact that most organizations are aware of the significance of strategically managing their Supply Chain (SC) they do not recognize that successful SC management rests on the performance of the staff in that SC.

For most organizations, it is mandatory to have the staff in exactly the right place at the perfect time when trying to fulfill their clients' requirements due to the primordial role of the HR in the SC management. From (Ammar, Benaissa and Chabchoub, 2013) HR scheduling is a crucial component that can certainly affect productivity and social environment. In addition, the significance of satisfying employees' desires in scheduling decisions has become highly recommended. Companies are

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progressively oriented to employee preferences (Bergh et al., 2013). According to (Koubaa, Elloumi and Dhoub, 2014) the HR management as a key element of companies' competitiveness has been emphasized recently. Indeed, using their talents correctly is essential to achieve the desired objectives.

The reminder of this paper is organized as follows: Section 2 reviewed the literature dealing with SSP. Section 3 provided a Mathematical Formulation (MF) of the SSSP while section 4 described the COA. Our empirical study as well as the obtained results were detailed in section 5. The final section, revealed the main conclusion and suggested some future perspectives.

2. LITERATURE REVIEW

It is often a complicated mission to devise solution methods that are general and able to sort out large integrated problems, when various sub-problems are recognized as NP-hard. A novel technique based on Simulated Annealing was applied in a framework suggested for a general SSP by (Kletzander and Musliu 2020). It was implemented to different benchmark instances for comparison and instances from a novel instance generator that allows the utilization of several Heuristic Algorithms (HA) and their application to a large scope of problems. The algorithm offers better results for all problems and might integrate novel constraints like the equity constraint achieving good results or it may even allow changing the constraints. The proposed framework also enables an easy integration of new moves as well as their reusability across different algorithms.

(Porto et al., 2019) evaluate the possible profits of integrating flexible labor into SSP. The solution technique elaborates, in a novel way, a mixed approach of labor flexibility unifies, first, flexible contracts, that enable the shifts length relaxation and the amount of working weekly hours of staff; and second polyvalent staff, employees specialized to work with diverse types of task, on the other. The Mixed Integer Linear Programming Model (MILPM) is drawn up to sort out the employees' number needed in every contract, and the number of employees who will be multi skilled and in which type of tasks. From The results it is demonstrated that the Hybrid Flexibility Strategy (HFS) proposed produce the best savings in the overall cost. Uniting single-skilled employees and polyvalent employees produce the best staff arrangements. In addition, it is illustrating that the most interesting contracts are those that have the shortest workdays.

To deal with Staff Scheduling (SS) in marine company, (Ammar, Benaissa and Chabchoub, 2013) proposed an MF of SSSP based on a Goal Programming (GP). Knowing that they are incapable to work out real cases using their advocated formulation, they shift to heuristic method advocating a Greedy Randomized Adaptative Search Procedure (GRASP) meta-heuristic which is constructed in two phases; First, the solution construction and then the improvement which is guaranteed by the authors through a Local Simple Research (LSR), then a Taboo Algorithm (TA) utilizing a real case data from a Tunisian ship-owner to validate their tests. For future works, the authors propose to use other heuristics or to include the ship scheduling to the problem.

In this context (Ammar, Benaissa and Chabchoub, 2014) adapted the Analytical Hierarchy Process (AHP) method to the MF of SSSP proposed in (Ammar, Benaissa and Chabchoub, 2013) to define weights of diverse objectives then they offered the adjustment of the GRASP meta-heuristic method to find the solution to the problem utilizing a real cases data adopted from a Tunisian ship-owner.

Also, in (Koubaa, Elloumi and Dhoub, 2016) and (Koubaa, Elloumi and Dhoub, 2014) papers the authors intend to resolve the NP-hard problem formed as the SSSP in a Tunisian company by the utilization of a meta-heuristics, called the Artificial Bee Colony (ABC), inspired by the food searching behavior of the honey bee in nature. The results display that the distribution of tasks using the ABC algorithm is equivalent to those provided by the two variant of the GRASP method in (Ammar, Benaissa and Chabchoub, 2013) in a less computational time in both low and high season. Furthermore, for the high season the result of the ABC algorithm outperforms the GRASP in coverage rates. From this perspective the authors propose to investigate in other heuristics while taking into account the staff preferences or the use of this method to other Scheduling Problems (SP).

As he mentioned, « To help non-initiated people with the analysis and modeling of SSP », (Blochliger, 2004) presented a modeling of scheduling problems which is general, so it might be applicable to a diversity of real-world problems, but he does not provide a complete survey of the subject and the literature. He took an instance of a hospital then presented and classified the data implicated in the scheduling problem including the identification of the parts that may be independent also the identification of items, time table blocks, jobs, costs, decision variables and gave the notations needed to the formulation of the objective function and constraints. Then he classified the constraints into nine types. He also defined the several parts of the objective function for the SP which are the cost, fairness and soft constraint violations.

(Ernst et al., 2004) provide a basic reference document that involves a survey of extended research guidance, some proposed models and solution approaches together with their implementation in the staff scheduling and restoring problems. This would help companies to provide the necessary equipment for their operations in a cost-effective way and satisfy their workers' preferences. In the same paper, the authors also developed a classification of SSP. We may finally conclude that the authors highlighted the fact that it is very hard to give an optimal solution combining the satisfaction of the employees' desires the workplace constraints, the minimization of costs and the assignment of shifts equitably among the staff.

According to (Ernst A.T. et al., 2004), «Staff Scheduling (SS) is specified as the action of creating optimized task timetable for staff. » It has awarded enhancing care in latest years. Also, from (Ernst A.T. et al., 2004), «the restoring problem include arranging qualified workers to perform a time reliant demand for diverse services while respecting industrial workplace arrangements and undertaking to fulfill individual work desires. » (Ernst A.T. et al., 2004) paper contained a survey of over 700 papers including different phases of the restoring process. Each of the reviews is categorized depending on their classification, their application area which followed the approach introduced in (Ernst et al., 2004) and their solution method (classified into 29 different categories).

(Heil, Hoffmann and Buscher, 2020) published a paper dealing with this SSP issue. They surveyed 123 papers on Railway Crew Scheduling (RCS) focusing on the most recent papers starting from the year 2000. The selected articles were classified according to some selected criteria by the authors such as solution method, crew type, objective function, among others. Then, they described some models that were used before and presented the objectives and constraints. Also, the authors categorized the alternative of solution methods presented in other works into heuristics, meta-heuristics, column generation and Integer Programming Methods (IPM). Additional research is still required to establish RCS models and methods adapted to easily and quickly changing circumstances.

The significance of satisfying employee desires in scheduling decisions gained more and more interest. Companies are progressively oriented to employees' preferences. (Bergh et al., 2013) paper contains a survey of SSP. It discusses the categorization methods in review papers and mentions that to classify staff members, the authors looked into labor contract (full-time or part-time workers), casual workers, specific skills, the crew (or team). The authors also mention the types of decisions to undertake in SSP, namely tasks assignment, groups assignment, and shift sequence assignment. Also, the SSP can be classified depending on the undertaken constraints or even on the adapted solution technique. Then an evaluation of the papers included in the literature treating various fields was carried out.

A very special SSP case was treated in (Hojati, 2018) paper where the author proposes a novel greedy heuristic solution method for the Shift Minimization Personnel Task Scheduling Problem (SMPTSP). The selection of the best assignment of tasks to one worker is obtained from iteratively treating the reduced problem. The Greedy Heuristic Method (GHM) has been tested on three sets of problems. The tests demonstrated that the GHM works better compared to the current solution methods and has the supplemental benefit of being capable to sort out very large instances quickly.

(Akbari, Zandieh and Dorri, 2013) developed a modeling of «part-time and mixed skilled SSP ». Such a module tries to raise the employees satisfaction considering the staff's availability,

priority preferences, seniority level, productivity, and the needed number of staff members for the tasks to be assigned. Simulated Annealing (SA) and Variable Neighborhood Search (VNS) were introduced to sort out the NP-hard problem. The results proved that the VNS achieves better than the SA features regarding the solution and the calculation time.

(Wright and Mahar, 2013) submitted a Centralized Nurse Scheduling (CNS) to enhance schedule cost while increasing the satisfaction of the nurses. The main contribution of this work is that it investigated «how centralizing cross-trained Nurses Scheduling (NS) across multiple units in a hospital may be utilized to decrease costs and increase nurses' satisfaction. ». The results showed that the centralization of the schedule in the two real case hospitals increases the nurse schedules desirability by around 34% and decreases overtime by about 80% while reducing costs by up to 11%. Moreover, the solution involves a linearization of the service constraints which can be considered as a contribution to the NS literature.

Various papers that deal with cases or/and models or/and approaches for Timetabling and restoring have already appeared, except that these publications do not form a structured domain which supplies a guideline for dealing with specific problem instances; neither does it afford to identify gaps that require further research. To tackle the issue (De Causmaecker and Vanden Berghe, 2012) presents a fundamental structure for the incorporated staff planning and restoring problem. They offer a formal detail for Short Term (ST) nurse restoring. The paper also presents a categorization of problems to be utilized for analysis and comparison.

Another paper treating the hospital sector was proposed by (Schoenfelder et al., 2019) in which the authors examined the usage of two quick-response methods. First the cross-trained float nurses' adjustments to the unit assignments and also the patients transfer between units and off-unit admissions within an NS model to support hospitals to handle patients' demand variations and enhance performance. A multi-stage stochastic programming model, that harmonizes initial per-shift NS decisions with fast response decisions was undertaken after watching patients' requirements. From the multiple contributions we can cite the costs reduction obtained from the Quick-response via the cross-trained nurses.

In this context (Lan et al., 2019) investigated the SP of physicians and medical staff (PMS). The authors define the problem, then present a modeling based on a hybrid meta-heuristic algorithm blending the Sines, Cosine Algorithm (SCA) with a VNS premised on Iterated Hungarian Algorithm (IHA) mainstreamed to sort out the PMS assignment. The experiment and the comparison results are also discussed in the paper. Relying on several computational tests, the PMS scheduling was created and was remarked to better fulfill the objectives than other comparable algorithms.

(Brucker, Qu and Burke, 2011) formulate a mathematical model of the SSP which covers particular characteristics of this problem, and they present some special cases then clarify the challenging parts in each case. The paper proposed some perspectives such as the development and testing Heuristics which assign feasible shifts to employees, construct schedules which allow task changes, and handle the total changes of tasks to minimize the number of task changes problem.

In their work, (Brucker and Qu, 2014) extended an existing Network Flow Model (NFM) to treat the situation where the staff members are not all skilled to accomplish all assigned tasks. This model was improved allowing the computation of employee shifts for a particular day. The authors firstly presented the formulation of (Robinson et al. 2005), developed the NFM, then discussed the possible further and combined extensions.

To settle the order in which the jobs and rest periods are assigned, in addition to the day-to-day assignment for each shift taking into consideration the objective of reducing the total number of required employees, (Caprara, Monaci and Toth, 2003) presented MF and solution algorithms for some SSP. The authors split the problem into two phases; first the working tasks order and the pattern for every employee were developed as a covering problem; second, the day-to-day assignment for each working period by every staff member is identified. The suggested approach is capable

of establishing the optimal solution of instances involving hundreds of employees over a 6-month working time interval.

(Koubâa et al., 2016) focused on Truck Driver Scheduling Problem (TDSP) in an attempt to publish a state of the art related to the latest works dealing with the TDSP starting from 2000. The authors identified four factors to the causes leading to the risks of crashes in the discussed papers.

The Staff scheduling (SS) and routing problem combines the vehicle routing problem and the SS which are NP Hard. In their paper (Yurtkuran, Yagmahan and Emel, 2018) presented an alternative of this problem with negligible walking distances and time windows, the authors formulate a unique-objective MILPM for the problem by combining two implicitly weighted goals to minimize the unbalanced workloads and the workforce. An enhanced Artificial Bee Colony (ABC) algorithm was proposed by the authors since the problem has a non-deterministic polynomial time severity. The authors compared the developed algorithm with diverse alternatives of ABC, and with particle swarm and more metaheuristic algorithms. The results show the superiority of the ABC algorithm and prove that the developed algorithm is able to reach precise results within short computational times.

(Beliën et al., 2013) studied how to allocate the workforce schedules of an aircraft maintenance company while reducing the labor costs. There are two necessary decisions to take, staff level required to fulfill the costumers' requirements and the scheduling decision. In this paper, the authors proposed an enumeration technique to sort out the Mixed Integer and linear Problem. The paper contains three contributions: it combines staffing and scheduling, allows a new formulation of the problem, and finally gave a possibility to decide in what time the maintenance of each flight may be carried out.

SSPs have been substantially modified over time, creating a diversity of constraints linked to flexible hours of staff, part-time staff, legal and organizational requirements, staff preferences, etc. Meanwhile, a great number of software packages have been provided with the aim to serve in SS. (Petrovic, 2019) suggested a classification of these software packages and enriched it with a discussion on the assistance degree they can provide to schedulers. Unfortunately, the existent software, does not profit from the richness of the formulated models and methods. Their main conclusion was that it is urgent to further engage with schedulers and software developers.

Some authors worked on the development of software for different real-world problem scheduling. In (De Causmaecker et al., 2004) paper, the eventual aim was "to create an agent-based framework that can deal with distributed staff scheduling". They gave a categorization of real SSP. They examined eleven companies and described their way of scheduling considering three parameters, namely staff and duties. From this classification, four categories of the scheduling problems can be outlined: permanent, mobility, fluctuation and project centered planning. Finally, the authors cited the required parameters for each type.

(Ertogral and Bamuqabel, 2008) presented an SSP in a call center in their study. The minimum number needed by the agents has been identified; and then, the sets of staff members were attributed to schedules utilizing optimization models upon the various scenarios related to the groups composition and agents' flexibility.

(Afshar-Nadjafi, 2021) paper provides a literature review that investigates multi-skilling and flexible employees in scheduling problems which is the practice of training employees to do a number of different tasks. It overviews the existing models and methods in this field from 2000 to 2020. This review starts with a general framework for multi-skilling, and then presented a comprehensive taxonomy for the literature of multi-skilling in SP. As for the solving methods, the main focus of the existing literature of multi-skilling in SP has been dedicated to project scheduling problems with 53.12% cases, mixed integer programming models with 54.2% cases and metaheuristics with 28.7% cases. As for the single objective function (68.8% of research dealt with this type), the main focus has been devoted for cost in 39.4% cases, and for the deterministic environment of the parameters in 85.5% cases, ranking at the top. It also turned out that 13.8% of the research papers have formulated models with two objectives and 17.6% of the research papers have created models with more than two objectives.

(Cildo, Mallor and Mateo, 2021) paper addresses a real physician scheduling problem in an Emergency Room (ER) considering the use of four categories of constraints, which are: supply and demand, workload, fairness and ergonomics. The purpose is to allocate types of shifts and workdays among all the doctors. Knowing that exact solution methods cannot sort out this difficult special problem for large instances, they shifted to the metaheuristic approach, using the GRASP method combined with the continuous Linear Programming (LP). To obtain an improved schedule, they iteratively applied the Variable Neighborhood Descent Search (VNDS) and the Network Flow Optimization (NFO). The computational study shows the superiority of their approach over the Integer Linear Programming (ILP) method. The obtained solutions by the software tool, used for generating one-year-ahead physician schedules, outperform the manually created schedules used previously. It is worth mentioning, however, that the generated solution was already in use.

3. MATHEMATICAL FORMULATION

In this section we presented the mathematical formulation developed in (Ammar, Benaissa and Chabchoub, 2013) which is a mathematical formulation of a real case of the SSSP in the SONOTRAK. It was proposed and tested with CPLEX; unfortunately, a real case cannot be resolved with the proposed mathematical formulation because of its NP- hard nature and dimension. This study was, therefore, launched at the point where the authors stopped with their real case problem. Our purpose was to provide a feasible solution and this is where the novelty of our research lies. Thus, we adopted their mathematical formulation described below and developed it on MATLAB 2018a to sort out this SSSP using one of the population-based meta-heuristics called Cuckoo Optimization Algorithm (COA). It is clear, then, that our contribution was the use of the COA as an alternative approach to their proposition allowing us to overcome the problem they faced with the NP hard version.

From (Ammar, Benaissa and Chabchoub, 2013) there exist multiple objectives in the SSSP. In this research study, we have adopted the same approach which can be enumerated as follows:

1. Reduce the deviation in total rest hours between every two successive jobs.
2. Reduce the deviation in total rest hours of every weekly break.
3. Minimizing the weekly break day's number.
4. Minimizing the deviation of the assigned number of each category of job regarding to the mean number of assignment.
5. Minimizing the deviation of the assignment number in every job.

The suggested schedule must meet those constraints:

1. Only one crew is assigned per job
2. The length of a weakly break is greater or the same as a minimal bound fixed by the expert.
3. The length of a break between two successive jobs is greater or the same as a minimal bound fixed by the expert.
4. Ensuring five successive workdays by a crew awards the crew members a weekly rest on day number six.
5. The crews who are not scheduled are those on furlough or those ensuring a technical break during that period.

Their mathematical program parameters and data are presented below:

BMin: The number minimal of rest hours between every two successive jobs.

BRMin: The minimal number of weekly break hours.

OptR: Optimal break between two successive jobs interval.

OptRH: Optimal weekly break interval.

M_{l,j}: The mean number of jobs 'j' of category 'l' to assign

$$M_{l,j} = \frac{\text{The sum of jobs } l \text{ to locate}}{\text{sum of crews}}$$

N_l: The mean number of jobs category 'l'

$$N_l = \frac{\text{The sum of jobs of category } l \text{ to assign}}{\text{sum of crews}}$$

D_{i,l,j}: The duration of the starting time of the job 'j' of category 'l' the workday 'i'

F_{i,l,j}: The duration at the finish of the job 'j' of category 'l' the workday 'i'

C_{i,k}: Availability indication that ensuring that the crew is free to do the action or not.

$$C_{i,k} = \begin{cases} 1; & \text{if the crew 'k' is on furlough or ensuring a technical break on the workday 'i'} \\ 0; & \text{otherwise} \end{cases}$$

M: A very big variable.

Their decision variables are presented below:

$$X_{i,l,j,k} = \begin{cases} 1; & \text{If the crew 'k' ensuring the job 'j' of category 'l' on workday 'i'} \\ 0; & \text{otherwise} \end{cases}$$

$$Y_{i,k} = \begin{cases} 1; & \text{If the crew 'k' is doing a job on workday 'i'} \\ 0; & \text{otherwise} \end{cases}$$

with:

$i \in \{1, \dots, I\}$ and I : days of the schedule

$l \in \{1, \dots, L\}$, L : the job types number

$J \in \{JI, \dots, JF\}$, JI : The first job index

JF : The last job index

$K \in \{1, \dots, K\}$, K : The crews' total number

$DN_{g,l,i,k} \geq 0$

$DP_{g,i,l,k} \geq 0$

$$\text{Minimize } \sum_{g=1}^4 \sum_{i=1}^I \sum_{l=1}^L \sum_{k=1}^K DN_{g,l,i,k} + DP_{g,i,l,k}$$

subject to:

Each job is ensured by only one crew:

$$1. \sum_{k=1}^K X_{i,l,j,k} = 1; \forall i, \forall l, \forall j$$

A crew is able to ensure only one job per workday:

$$2. \sum_{l=1}^L \sum_{j=JI}^{JF} X_{i,l,j,k} \leq 1; \forall i, \forall k$$

If the crew is ensuring a job, it is in service:

$$3. \sum_{l=1}^L \sum_{j=JI}^{JF} X_{i,l,j,k} - Y_{i,k} = 0; \forall i, \forall k$$

A crew is assigned if it is not on furlough, or it does not ensure a technical break:

$$4. Y_{i,k} + M \cdot Z_{i,k} \leq 0; \forall i, \forall k, Z \in \{0,1\}$$

$$5. C_{i,j} - M(1 - Z_{i,k}) \leq 0; \forall i, \forall k, Z \in \{0,1\}$$

Ensuring five successive workdays earned the crew a break in the next day (day six) which is a weekly day break:

$$6. \sum_{i=1}^6 Y_{i,k} = 5; i \in \{1, \dots, I-6\}, \forall k$$

$$7. Y_{(i+6),k} - M \cdot Z_{i,k} \leq 0; \forall i, \forall k, Z_{i,k} \in \{0,1\}$$

$$8. \left(\sum_{i=1}^{i+5} Y_{i,k} - 4 \right) - M \cdot (1 - Z_{i,k}) \leq 0; \forall i, \forall k, Z_{i,k} \in \{0,1\}$$

The break interval between two jobs should be greater than a minimal bound:

$$9. BMin - \left[\sum_{j=JI}^{JF} (D_{i,l,j} \cdot X_{i,l,j,k}) - \sum_{p=JI}^{JF} (F_{(i-1),l,p} \cdot X_{(i-1),l,p,k}) \right] Y_{i,k} - Y_{(i-1),k} - M \cdot Z_{2i,k} \leq 0; \\ \forall i, \forall l, \forall k, Z_{2i,k} \in \{0,1\}$$

$$10. \left[\sum_{j=JI}^{JF} (D_{i,l,j} \cdot X_{i,l,j,k}) - \sum_{p=JI}^{JF} (F_{(i-1),l,p} \cdot X_{(i-1),l,p,k}) \right] - M(1 - Z_{2i,k}) \leq 0; \forall i, \forall l, \forall k, Z_{2i,k} \in \{0,1\}$$

The weekly break interval should be greater than a minimal bound:

$$11. BRMin - \left[\sum_{j=JI}^{JF} (D_{i,l,j} \cdot X_{i,l,j,k}) - \sum_{p=JI}^{JF} (F_{(i-2),l,p} \cdot X_{(i-2),l,p,k}) \right] Y_{i,k} - Y_{(i-2),k} - (1 - Y_{(i-1),k}) - M \cdot Z_{3i,k} \leq 0; \forall l, \forall k, i \in \{2, \dots, I\}, Z_{3i,k} \in \{0,1\}$$

$$12. \left[\sum_{j=JI}^{JF} Di, l, j .Xi, l, j, k - \sum_{p=JI}^{JF} (F(i-2),l, p .X(i-2), l, p, k) \right] Yi, k Y(i-2), k - (1- Y(i-1), k) - M (1-Z 3i,k) \leq 0 ; \forall l, \forall k, i \in \{2, \dots, I\} Z 3i, k \in \{0,1\}$$

Reduce the deviation in total break hours between every two successive jobs:

$$13. \left[\left(\sum_{j=JI}^{JF} Di, l, j .Xi, l, j, k - \sum_{p=JI}^{JF} F(i-1),l, p .X(i-1), l, p, k \right) .(Yi, k Y(i-1), k) - (OptR Yi, k Y(i-1), k) \right] + DN1, i, k - DP1, i, k = 0 ; \forall l, \forall k, i \in \{1, I-1\}$$

Reduce the deviation in total break hours of each weekly break:

$$14. \left[\left(\sum_{j=JI}^{JF} Di, l, j .Xi, l, j, k - \sum_{p=JI}^{JF} F(i-2),l, p .X(i-2), l, p, k - OptR H Yi, k \right) Yi, k Y(i-2), k - (1- Y(i-1),k) \right] + DN2, i, k - DP2, i, k = 0 ; \forall l, \forall k, i \in \{2, I\}$$

Minimizing the deviation of the assigned number of each category of jobs regarding to the mean number of schedules:

$$15. \sum_{l=1}^L \sum_{j=JI}^{JF} Xi, j, k - N l + DN3, i, k - DP3, i, k = 0 ; \forall l, \forall k$$

Minimizing the assignments number deviation of each job's category regarding to the mean number of schedules:

$$16. \sum_{i=1}^I (Xi, l, j, k - M l, j + DN4, l, j, k - DP4, l, j, k = 0 ; \forall l, \forall k, j$$

4. CUCKOO OPTIMIZATION ALGORITHM (COA)

The Optimization Problem (OP) is sorted out through the use of a number of steps known as the Optimization Algorithms (OAs) from which we can cite the ones designed underpinned on nature-inspired concepts, and deal with the choice of the best alternative of the afforded Objective Functions (OF). OAs can be heuristic or metaheuristic approaches. The metaheuristic may be categorized as Evolutionary algorithms from which we can cite the following examples: Genetic programming, genetic algorithm, differential evolution and harmony search; Trajectory-based algorithm (like Taboo search, Simulated annealing), and Swarm-based algorithms. Among these metaheuristic algorithms, the COA was our main concern in this work.

The COA is among the most recent, dominant, robust and popular bio-inspired algorithms that was designed in 2009 by (Rajabioun, 2011). The life of a cuckoo bird family is the origin inspiration of this algorithm. This bird has a belligerent breeding behavior. They pose their eggs in the other birds' nest and throw away the already existing host eggs to increase the hatching probability of their own eggs.

4.1 Initial Habitat of Cuckoo Generation

From (Joshi et al., 2017), in order to sort out an O.P, it is required that the problem variables values be constituted as an array, in COA it is known as "habitat". In an Nvar- sized O.P, a habitat is an

array of $1 \times Nvar$, symbolizing current living location of the cuckoo. This array is determined as: $habitat = [x_1, x_2, \dots, x_{Nvar}]$.

Each of the variables values ($x_1, x_2, \dots, x_{Nvar}$) is number of floating points. The profit (objective) function 'fp' at a habitat of ($x_1, x_2, \dots, x_{Nvar}$) is the habitat profit. As it is viewed, the fp is maximized in COA. In the case of a cost minimization problem: Profit = Cost (habitat) = $fc(x_1, x_2, \dots, x_{Nvar})$; in the beginning of the OA, an applicant habitat matrix of size $Npop \times Nvar$ is created. Next, for each of the initial cuckoos' habitats a few numbers of eggs (randomly generated) are assumed. Knowing that between 5 and 20 eggs are laid by each cuckoo in nature, 5 is used as the lower limit (var low) commitment to every cuckoo at several iterations and 20 is the upper limit (var hi). The cuckoos also lay their eggs with maximizing the total distance from their own habitat. The maximum distance is recognized as the "Egg Laying Radius (ELR)". It must be noted that every cuckoo has this ERL which is calculated as follows:

$$ERL = \alpha \times \frac{\text{Number of current eggs of cuckoo}}{\text{Sum of eggs}} \times (\text{var } Hi - \text{var low})$$

where α assumed to hold the ERL maximum value.

α : integer

4.2 Cuckoos' Egg Laying Style

Every one of the cuckoos randomly initiates her eggs laying inside her ELR. Few of the placed cuckoos' eggs are dissimilar to the eggs belonging to the host birds; once they are discovered, they are kicked by the host birds out of their nest. So, $p\%$ of all the placed eggs (10% in average), with the least profit value are murdered. These eggs get no opportunity to hatch and grow. The remainder of the eggs in the host nests, hatch and are then nourished by the host birds. An additional attractive aspect about the cuckoo egg laying is that there is only one egg in the nest that has the opportunity to grow. Considering that, when the egg of the cuckoo hatches and the new chick appears, the eggs of the host birds will be thrown out of the nest by the chicks. And even if the eggs of the host birds hatch sooner, it is always the cuckoo chick that survives because it consumes most of the food carried to the nest by the host bird causing the hunger and death of the other chicks. After some days, only the cuckoo chick remains and the host birds chicks die. (Joshi et al., 2017)

4.3 Cuckoos' Immigration

After the cuckoos' chicks get bigger, they stay in their area for a little while. Then, once the egg laying season approaches they depart to a more appropriate area where they can find nests with similar eggs to their own and with better opportunities for food for their new chicks. After the cuckoo gangs are formed in several areas, the environment with better profit value is chosen as the target for the immigration of the other cuckoos. Therefore, the Mean Profit Value (MPV) needs to be measured. Next, a goal group is established with the maximum value of those MPV, and the best habitat of the group becomes the goal habitat for the cuckoo. When searching for the target habitat, the immigrant cuckoo flies a distance ($\lambda \%$) then deviates (ϕ radians) from the goal point. This habit helps the cuckoo bird search access extra positions in all societies. For each cuckoo, two parameters are fixed as:

$$\Lambda \sim U(0, 1)$$

$$\phi \sim U(-\omega, \omega)$$

where, the first means that λ is randomly chosen number between 0 and 1. And the second is a parameter to limit the target habitat deviation (generally chosen as $\pi/6$ rad). When the immigration of all cuckoos into target position occurs and the new habitats are established, every grown cuckoo has some eggs. Then, taking into account the eggs' number devoted to every bird, an ELR is measured for every cuckoo. Subsequently, the new egg laying process is launched once again (Joshi et al., 2017).

4.4 Removing Cuckoos in the Most Unfavorable Habitats

There should be a balance in the bird's population; thus, there is N_{max} values that control and limit the maximum number of the living cuckoos. The rest are killed by predators or are unlucky to detect a good nest for the unborn cuckoos. So, when developing the mathematical module, the N_{max} number represents those which have greater profit values whereas the rest demises (Joshi et al., 2017).

The general flowchart of COA is clearly presented in the figure proposed by (Rajabioun, 2011).

5. PROPOSED METHODOLOGY

In this section we described our research methodology using the COA originally proposed by (Rajabioun, 2011). The use of the COA aimed to select the best schedule with the lowest objective function value from the multiple solutions found after running our algorithm. As a reminder, we adopted the same mathematical formulation proposed in (Ammar, Benaissa and Chabchoub, 2013) to deal with the SSP in the marine company called SONOTRAK and developed it on MATLAB 2018a

Figure 1. COA flowchart (Rajabioun, 2011)



to sort out this SSSP using one of the population-based meta-heuristics called Cuckoo Optimization Algorithm (COA). It is clear, then, that our contribution is the use of the COA as an alternative approach to their suggestion allowing us to overcome the problem they faced with the NP-hard version of the problem. An algorithm that presents the novel strategy proposed was described and detailed along with the equations used.

6. CASE STUDY

To check the efficiency of the COA in overcoming the considered problem, and considering the various results achieved by both of the GRASP and by ABC methods, we performed experiments on the same tests proposed by (Ammar, Benaissa and Chabchoub, 2013), (Ammar, Benaissa and Chabchoub, 2014), (Koubaa, Elloumi and Dhoub, 2014) and (Koubaa, Elloumi and Dhoub, 2016). Two test sets on the seafaring staff scheduling were performed in the Tunisian company called SONOTRAK: the first was achieved at the low season whereas the second was carried out at the peak season during heavy traffic.

7. EXPERIMENTS AND RESULTS

7.1 Inputs Description

In this part, we introduced the various inputs and outputs of our application.

7.1.1 *fonctionObj Script*

This file contains all the four objective functions to calculate the value of the fitness.

7.1.2 *intSolution Script*

This file allows assigning the different posts to the staff in all the days of a given month.

7.1.3 *restIntervalPerTeam Script*

It calculates all the values of the rest between every two consecutive posts.

7.1.4 *reposEntrePoste Script*

This file enables us to identify the minimum and the maximum values of rest between every two-consecutive posts for every team.

7.1.5 *calcul_variance_reposEntrePoste Script*

It calculates the variance in all the calculated values of rest between every two-consecutive posts.

7.1.6 *tabReposEntrePoste Script*

This file allows us to display a table that contains all the minimum and maximum values of rest between every two-consecutive posts, as well as the mean and the variance of all the values calculated and to find the minimum and the maximum values displayed in the table for all the teams.

7.1.7 *WeeklyRestInterval Script*

It calculates all the values of weekly rest when it occurs.

7.1.8 *reposHebdomadaire Script*

This file enables us to identify the minimum and the maximum values of weekly rest for each team.

Algorithm 1. Proposed COA

Beginning of the algorithm

1. parameters initialization : habitat, eggs, max_eggs, var, alpha and epoc.
2. population initialization : numberOfTeam_total, numberOfTeam_conge, numberOfTeam_arretTechnique, numberOfTeam_fonctionnel, numberOfDays, Month, year, postNumber ,heureDebutpost, heureFinpost, heureVoyage1, heureVoyage2, nbr_post, num_post.
3. static variables initialization:


```

repos_entre_poste = zeros(numberOfTeam_fonctionnel, 4);
repos_Hebd = zeros(numberOfTeam_fonctionnel, 4);
nbrRepos_Moy_Var = zeros(numberOfTeam_fonctionnel, 4);

daysOfMonth = strings(numberOfDays, 1);
for i=1:numberOfDays
    dateConcat = strcat(num2str(year), '-', num2str(month), '-', num2str(i));
    date = datetime(dateConcat, 'InputFormat', 'yyyy-MM-dd');
    %result(i,1) = date;
    daysOfMonth (i,1) = date;
end

```
4. while((fitness > bestFitnessValue_FoundedInTheLiterature || numberTeamsNotAffected > 1)&& iteration < 1000)
5. dedicate a few number of eggs for each cuckoo (insertion of a random number of eggs)


```

curr_eggs = randi(eggs,1,1); % random number between 2 and 20

```
6. let the cuckoos lay their eggs in their ELR (calculate the total number of eggs laid)
7. calculate the ELR for each cuckoo


```

for compteurHabitat = 1:habitats
    numero=habitat_eggs (compteurHabitat,1);

    ELR (compteurHabitat,1)=alpha*(habitat_eggs (compteurHabitat,1)/total_eggs)*(
    var(2)-var(1));

    display(strcat('habitat numero:[',num2str(compteurHabitat),'] having eggs
    :[',num2str(habitat_eggs (compteurHabitat,1)), ']' ELR
    :[',num2str(ELR (compteurHabitat,1)), ']''))
end

```
8. determine the bad egg in all the habitats which has the maximum profit (evaluate the cuckoos of the population and kill the eggs detected by their host)
9. search for a good solution in the new eggs laid (find the best habitat and destroy the bad habitats)
10. display of the best habitats and the best egg (immigrate the cuckoos of the new population to the best habitat)


```

if(cost_best < Meilleur_fit) %for the first iteration: Meilleur_fit = inf;
    E_time=toc;
    Meilleur_fit=cost_best;
end
cost_best=inf;
for compteurHabitat=1:habitats
    for compteurHabitatEggs=1:habitat_eggs (compteurHabitat,1)
        if(cost_best > H (compteurHabitat,compteurHabitatEggs,2))
            cost_best=H (compteurHabitat,compteurHabitatEggs,2);
            best_pos=compteurHabitatEggs;
            best_hab=compteurHabitat;
        end
    end
end

```
11. return the best solution


```

disp('best possible output')
display(Mat_1);
title(strcat('fitness value:',num2str(best_fitness),' , best sol execution
time:[',num2str(E_time),' ]sec'));

```

End of the algorithm.

7.1.9 *calcul_variance_reposHebd Script*

It calculates the variance in all the calculated values of weekly rest for all the teams.

7.1.10 *tabReposHebdomadaire Script*

This file allows us to display a table that contains all the minimum and maximum values of the weekly rest for all the teams, as well as the mean and the variance of all the values calculated and to find the minimum and the maximum values displayed in the table for all the teams.

7.1.11 *tabNAF Script*

If the coverage rate is under 100%, this file displays the day, the team and the post not assigned.

7.1.12 *tabNbrAffectPost Script*

This file displays the number of affected posts for each team in each post.

7.1.13 *tabNbrJoursRepos Script*

Displays the number of rest days for each team.

7.1.14 *fonctionOpt Script*

If the first assignment does not succeed in assigning one of the posts to a team, this function allows to perform another assignment to permute with another team the non-assigned post with an assigned one if possible.

7.1.15 *getOneResult Script*

This File introduces the various results of the scheduling according to a calendar where a unit presents the type of the post allocated to a team given on a defined date.

7.1.16 COA

This file generates all the scheduling results and finds the best solution from all the schedules found.

7.2 Programming Environnement

This approach was developed on MATLAB 2018a on a laptop with the following characteristics:

- Processor: Intel® Core™ i3.
- RAM: 4 GO.
- Graphic Card: Intel® HD Graphics 5500.
- Hard Disk: 250 GO

7.3 Results

The results of the first test show that scheduling, using COA, are much the same as those obtained by the two versions of GRASP method and the ABC method.

Schematic 1 shows the value of the objective function found using COA for the first scenario.

Tables 1 and 2 display the comparison between four scheduling results generated by:

1. The GRASP method with simple search
2. The GRASP method with Taboo search
3. The ABC
4. And Cuckoo Optimization Algorithm (COA)

Figure 2. The objective function value obtained using COA for the low season

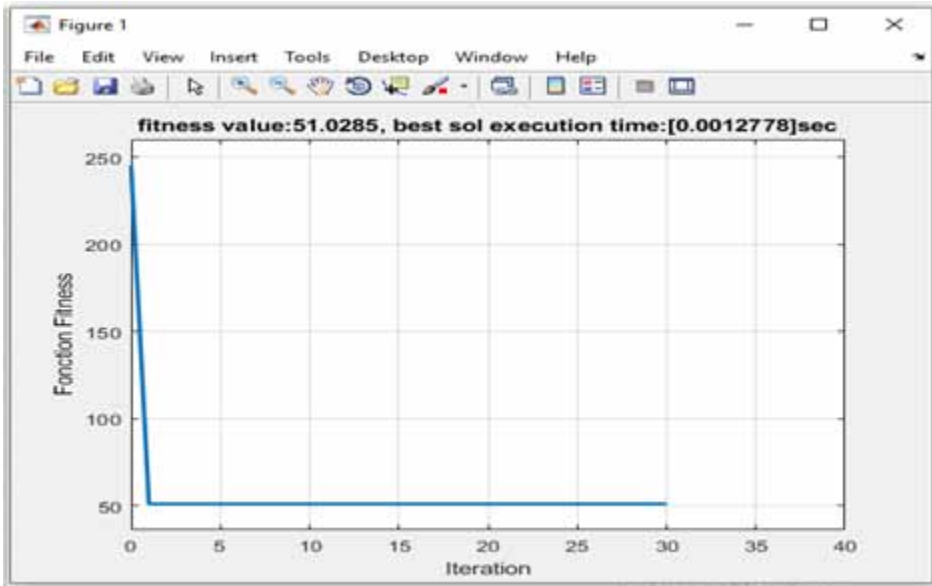
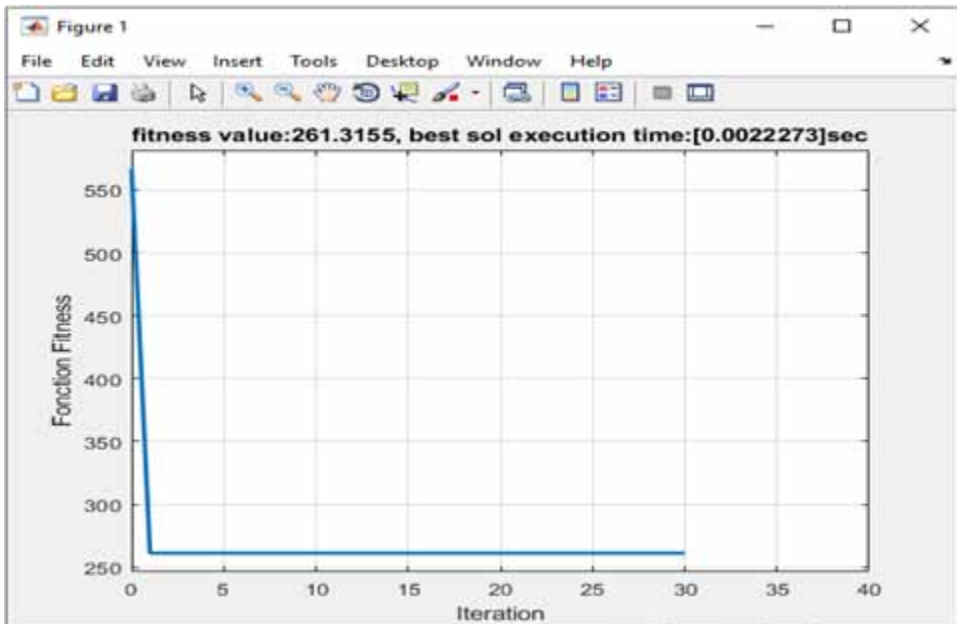


Figure 3. Objective functions obtained using COA at the traffic peak



Schematic 2 displays the objective function value found using COA for the second test. The COA does not seem to be more effective than the GRASP and ABC methods in the first case (low season). We, therefore, note that in the second test (peak season), it reached better solutions than those found by the GRASP and ABC methods.

Table 1. The comparison between the four assignments for the low period

Criteria		Break between posts		Weekly rest		Number of rest days		Total Post		Covering rates	Resolving Time (μ seconds)	Objective Function value
		Min	Max	Min	Max	Min	Max	Min	Max			
GRASP (simple search)	Min	11,5	11,5	50	50	5	6	5	6	100%	14,000,000	51,0258
	Max	14,25	14,25	50	50							
	Means	13,13	13,13	50	50							
	Variance (VAR)	1,07	1,07	0,00	0,00							
GRASP (taboo search)	Min	11,5	11,5	50	50	5	6	5	6	100%	12,000,000	51,0258
	Max	14,25	14,25	50	50							
	Means	13,13	13,13	50	50							
	VAR	1,07	1,07	0,00	0,00							
ABC algorithm	Min	11,5	11,5	50	50	5	6	5	6	100%	16	51,0258
	Max	14,25	14,25	50	50							
	Means	13,13	13,13	50	50							
	VAR	1,07	1,07	0,00	0,00							
COA	Min	11,50	11,50	50	50	5	6	5	6	100%	1277.8	51,0258
	Max	14,25	14,25	50	50							
	Means	13,125	13,125	50	50							
	VAR	1.01563	1.01563	0,00	0,00							

Table 2. Comparison between the four schedules for the traffic peak

Criteria		Break between posts		Weekly rest		Number of rest days		Total Post		Covering rates	Resolving Time (μ seconds)	Objective Function value
		Min	Max	Min	Max	Min	Max	Min	Max			
GRASP (simple search)	Min	10	11,5	41	41,75	5	6	0	6	92,37%	27,000,000	—
	Max	26	30,5	41,75	41,75							
	Means	15,49	17,31	41,3	41,75							
	VAR	15,72	51,99	0	0,19							
GRASP (taboo search)	Min	10	11,5	27	41,75	5	6	0	6	94,07%	36,000,000	—
	Max	26	30,5	41,75	41,75							
	Means	15,75	17,38	38,5	41,47							
	VAR	20,19	60,48	38,5	41,75							
ABC algorithm	Min	10	10	26,5	40,5	5	6	0	6	100%	32	280,20679
	Max	24,5	40,5	40,5	53,5							
	Means	14,75	16,55	32,5	44,2							
	VAR	18,57	41,07	0,07	63,41							
COA	Min	10	12	34	47,5	5	6	0	6	100%	2227.3	261,3155
	Max	16	18,5	36,5	49							
	Means	13,25	15,45	35,5	47,5							
	VAR	3.7925	31.05	1,35	66,85							

To check the efficiency of COA in overcoming the NP-hard problem, which is the Seafaring Staff Scheduling Problem (SSSP), two sets of experiments were performed on the same tests proposed by (Ammar, Benaissa and Chabchoub, 2013), (Ammar, Benaissa and Chabchoub, 2014), (Koubaa, Elloumi and Dhouib, 2014) and (Koubaa, Elloumi and Dhouib, 2016). The first experiment was achieved during the low season whereas the second was carried out over the peak season characterized by heavy traffic.

In our case study, COA-based scheduling has not shown better results for the first scenario (low season) compared to the two versions of GRASP and ABC methods. However, it allowed for better results for the second scenario (pic of the traffic).

This paper therefore provided three main contributions, First, the application of the Cuckoo Optimization Algorithm (COA) to solve this Seafaring Staff Scheduling Problem (SSSP) generating very satisfactory results.

The two other contributions are highlighted by the achieved comparison between the four used scheduling methods. On the one hand, the COA outperformed the other used methods since it offered more satisfactory results than those reached by the two versions of GRASP methods mainly in terms of maximized coverage. On the other hand, the total posts to be assigned was increased by one compared to the ABC, and the fitness value provided by the COA was smaller than that of the ABC method.

8. CONCLUSION

The established COA relies on nature-inspired ideas and tackles the problem through choosing the best alternative given by an objective function according to (Shehab, Khader and Al-Betar, 2017). In this context, we proposed to sort out an NP-Hard problem faced by SONOTRAK, a Tunisian maritime company, which is the SSSP that requires the utilization of meta-heuristics approach to find good solutions in less computational time. (Boveiri and Khayami, 2020) proposed a comprehensive evaluation study on some basic metaheuristics, and the Cuckoo Optimization Algorithm is among them; they suggested that it is adequate for those problems needing fast decisions.

In this context, we compared our results using COA with those found by GRASP methods applied by (Ammar, Benaissa and Chabchoub, 2013) and (Ammar, Benaissa and Chabchoub, 2014); and by the ABC method applied by (Koubaa, Elloumi and Dhouib, 2014) and (Koubaa, Elloumi and Dhouib, 2016). Our paper offers three major contributions; the first lies in its pioneer use of one of the population-based meta-heuristics called Cuckoo Optimization Algorithm (COA) to solve the Seafaring Staff Scheduling Problem (SSSP) in SONOTRAK.

The second was the fact that our proposed approach established a feasible solution that overcomes the problem faced by the two GRASP method versions with the NP-hard version of the problem.

As for the third contribution, it consists in the improvement of the objective function value compared to the results achieved by the ABC method and the two GRASP method versions, in addition to its success in increasing the number of assigned posts by one.

As a future perspective, we suggest using the studied method to sort out other SPs in other fields. We also think of applying our method to ship allocation to crew where the aim is to minimize the ships rotation rate.

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