On Allocation and Transferring of Ship-based Aircraft with Simulated Annealing Genetic Algorithm

Qin-hui LIU, Jiang LI, Xiang-lei MENG, Cai-yun LIU and Neng-jian WANG*
College of Mechanical and Electrical Engineering, Harbin Engineering University, Harbin, 150001, China
*Corresponding author

Keywords: Allocation and transferring, Scheduling, Simulated annealing genetic algorithm

Abstract. Allocation and transferring of Ship-based aircraft on deck are essential to sortie generation rate. For completing reasonable dispatching scheduling which is obtained under the constraints of deck space, auxiliary equipment and association among diverse operations, etc., a mathematical model of allocation and transferring is proposed. Then, Simulated Annealing Genetic (SAG) algorithm is established that can be used to get optimum solution of the mathematical model. Under the mathematical model, a case is generated and the result of the case study shows that the algorithm can meet the requirements of aircraft dispatching scheduling effectively.

Introduction

Carrier-based aircrafts need to be serviced, refueled, and rearmed before they can take off and carry out their missions [1]. Before executing maintenance tasks, aircraft must be transferred to suitable position as soon as possible. The traditional method used by America and Russia is to custom scheduling by manual work, which depends on the experience of scheduler heavily [2]. Recently, scholars study the scheduling problem with various methods. Michaels etal. First proposed the concept of intelligent digital deck scheduling system [3]. The United States Navy developed Aviation Data Management and Control System (ADMACS) [4] and Integrated Shipboard Information System (ISIS) [5] to overcome the defects of low efficiency. In addition, a lot of other methods are applied to study scheduling problems, such as Queueing Networks [6], Petri Network [7], Fuzzy Logic and Reinforcement Learning [8], Particle Swarm Optimization [9] and Genetic Algorithm (GA) [10, 11].

In consideration of the limitation of service resources and work space, the aircraft allocation and transferring problem should belong to the Resource-Constrained Project Scheduling Problem (RCPSP). In order to quickly develop a reasonable scheduling plan and improve the efficiency of the plan as much as possible, SAG algorithm is proposed, which contains the strong points of Genetic Algorithm and Simulated annealing algorithm and is of superiority in performance, efficiency and reliability.

The rest of this work is organized as follows: In Section 2, a mathematical model of scheduling process is developed. The assumptions, constrains and the object function are put forward. In section 3, the SAG algorithm is used to generate and optimize the scheduling. In section 4, the mathematical model and algorithm is verified through a case study. In section 5, the conclusion is given out by summarizing the work of this paper and some guides for further work are pointed out.
Mathematical Modeling

The problem of ship-based aircraft dispatching scheduling can be described as follows: \( m \) aircrafts are going to be moved to \( n \) target positions (\( n \geq m \)) through \( k \) tractors (\( k < m \)). And a series of maintenance tasks should be completed before each aircraft takes off. Optimal scheduling is to find the right service station and resource to allocate and transfer the aircrafts in right time. This section elaborates the problem based on the following assumptions:

1. There are a set of crews and tractors on the deck, and the crews and tractors are ready in the right place before the scheduling begins.
2. During the process of scheduling, auxiliary equipment's damage is not considered.
3. The time of staff tether aircraft and tractor to each position is constant.
4. When all tractor returns to the initial position (starting point), the scheduling is terminated.
5. It is not taken into consideration that if crews return to their own locations or not.
6. The aircraft and tractors are allowed to wait and to keep infinite buffer time before scheduling.
7. A team can only guarantee one aircraft at the same time.
8. Unexpected events and accidental events are not considered.
9. The speed of empty tractor is 2 times of that has been loaded.
10. Path obstacles are not considered; the arc length represents begin-end positions distance.

The objective function of the problem is given by

\[
\min \left( \max ET_i \right). \tag{1}
\]

s.t.

\[
ST_i = 0. \tag{2}
\]

\[
ST_i - ST_{i-1} \geq t, \quad 2 \leq i \leq m. \tag{3}
\]

\[
ST_j - ST_i \geq T_i, \quad \forall j \notin S_i, \quad 1 \leq j < i \leq n. \tag{4}
\]

\[
\sum_{ST_i \in A_{ST}} r_i \leq k, \quad 1 \leq i \leq m, \quad k < n. \tag{5}
\]

\[
T_i \geq 0, \quad 1 \leq i \leq n. \tag{6}
\]

Where \( ET_i \) is the finish time of scheduling about aircraft \( i \), \( ST_i \) is the start operation time of aircraft \( i \), \( t \) is the safety time interval, \( T_i \) is continuous operation time of aircraft \( i \), \( S_i \) is the collection of aircraft that are not be transferred, \( A_{ST} \) is the collection of aircraft that are being transported, \( n \) is the total number of aircraft, \( m \) is the sum of position, and \( r_i \) is the total number of tractors that are executing task.

In order to minimize the total time on the scheduling, formula (1) is established, and \( \max ET_i \) is the time that the last aircraft reaches target position after completing tasks. In the light of problem assumptions, start time of the scheduling is zero, which is shown with constraint (2). Formula (3) shows the safe interval between adjacent positions. Formula (4) shows the order constraint of the operations, the start time of the latter can’t be set before the end date of the former. Formula (5) shows the constraint of resources.
It indicates that the number of tractors that are executing task cannot exceed the 
maximum number $k$. Formula (6) shows the domain of the operation time.

**SAG Algorithm**

Work mechanisms and work process of the SAG algorithm are explained in this section. The problem of this paper is solved by the follow basic steps. Fig.1 illustrates the flowchart of the SAG algorithm.

![Flowchart of the SAG algorithm.](image)

**Step 1. Encoding**

Chromosome is composed by real number, and it was divided into m segments by $M$ aircraft. The gene of genetic algorithm contains two parts: gene locus (gene position in the chromosome) and allele (gene value) [12]. Gene locus represents for priority of aircraft scheduling, gene value is numbered in the order of the plane identification, tractor identification and station identification. According to the encoding method, each chromosome can express a concrete aircraft scheduling result. Such as 215, 537, 854 can be illustrated as follows: first of all, No.2 aircraft is sent to No.5 terminal station by No.1 tractor; then, No.5 aircraft is sent to No.7 terminal station by No.3 tractor; finally, No.8 aircraft is sent to No.4 terminal station by No.5 tractor.

**Step 2. Initial Population**

The method of random probability is adopted to generate the initial population. And the initial population consists of 50 individuals.

**Step 3. Fitness Function**

The fitness function of this paper is the objective function, which is shown in formula (1). The goal is to minimize the time spent in scheduling.

**Step 4. Choice**

The roulette is used to select the individuals in the population. The probability $P_i$ of individuals will be selected is given by

$$p_i = \frac{f_i}{\sum_{i=1}^{M} f_i}$$

(7)

Where $M$ is population size, $f_i$ is the fitness of the $i$th individual.

**Step 5. Crossover**

The crossover operation is not to exchange genes between two chromosomes but to exchange different gene segments on the same chromosome, so as to ensure the legitimacy of the solution. The principle of crossover is shown in Fig.2.

**Step 6. Variation**
Operation of variation means that the exchange of values of any two gene locus. The Variation operation ensures the new solution is a feasible scheduling after decoding process. The variation process is shown in Fig.3.

Figure 2. Crossover process. Figure 3. Variation process.

Step 7. Iterative Process of SA algorithm

The new solution and fitness values are generated according to SA algorithm, which is obtained by the method of the combination of 2-transformation and 3-transformation. Solution i is replaced by new solution j according to Metropolis criterion.

Transition probability \( P_k \) is given by

\[
P_k(i \Rightarrow j) = \begin{cases} 
1, & \text{while } f(i) < f(j) \\
\exp \left( \frac{f(i) - f(j)}{T} \right), & \text{others} 
\end{cases}
\]  (8)

Where \( i \) is the current solution, and \( j \) is the new solution produced in the iterative process. If \( f(j) \) is smaller than \( f(i) \), the new solution \( j \) is accepted, otherwise a random number between [0,1] is generated. If the random number is smaller than \( P_k \), the new solution \( j \) is accepted, otherwise the solution \( i \) is accepted. Metropolis criterion enhances the global search ability of SA algorithm. If the value of \( f(j) \) is invariant for consecutive 20 times, the temperature is updated.

Temperature updating function is given by

\[
T = T_0 \times (0.99^{g^{-1}})
\]  (9)

Where \( g \) is genetic algebra, \( T_0 \) is initial temperature, \( T_0=1000 \), and \( T \) is the current temperature. If the value of \( f(j) \) is invariant for consecutive 50 times, SA algorithm terminates.

If the fitness value based on SA algorithm is smaller than the former based on GA, the new solution generated on the basis of SA algorithm is accepted, otherwise the previous solution is adopted. This way is verified to avoid low efficiency and local optimum. SAG algorithm terminates until the stopping criterion is met, otherwise jump to step 4. The iteration of GA is performed 200 times, then SAG algorithm terminates.

Case Study

The solution of specific case is generated according to the mathematical model and improved genetic algorithms. Then, it is compared with the solution based on human
heuristic rule so as to validate the mathematical model and improve algorithms. The simulation scenario is shown as follows: There are 7 aircraft that need to be transported to suitable position. It only exists 4 tractors on deck, which named after Cr. Station named after Ai, Fk or Mj. Aircraft and tractors are arranged on the deck of aircraft carrier initially. Deck layout is shown in Fig 4. The aircraft 22, 21, 20, 9, 10, 11, 33 will be moved, its starting positions are A22, A21, A20, F4, F3, F2, F1 and its target positions are A35, A33, A32, A31, A30, A29, M6, M2. The numbers of tractors are C1, C2, C3, C4. The value of safety time interval is 50 seconds.

The approximate optimal solution is generated when the population evolves to the end of the 92th according to improved genetic algorithm. Individual fitness curve is shown in Fig 5 Line 1 represents the average time of scheduling each generation and line 2 indicates the optimal operation time of each generation.

The Gantt chart of scheduling is shown in Fig 6. The scheduling time based on the improved Genetic Algorithm is 19.6% less than that based on heuristic rules. The time spent on the scheduling plan based on heuristic rule is shown in Fig 7. The performance of the improved Genetic Algorithm on optimizing scheduling works very well.

Conclusions

In order to develop and optimize the scheduling of allocation and transferring on aircraft, taking the constraint of resource into consideration, this paper provides a mathematical model. SAG algorithm is applied to solve this problem. A specific case is solved according to the mathematical model and SAG algorithm which has been proved to be highly efficient. However, only one scenario is tested, more scenarios and improved versions of the algorithm shall be verified in the future.

Acknowledgement

This research was supported by the Heilongjiang Natural Science Foundation (QC2016063), Scientific Research Foundation for the Returned Overseas Chinese
Scholars (160070130003), State Education Ministry and the Fundamental Research Funds for the Central Universities (GK2070260117).

References


