ISSN: 2688-8653

Aerial Refueling Plan Optimization Model and the Solution of GA

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Abstract

Aerial refueling area configuration is a key link in the process of air refueling mission. This paper uses the genetic algorithm, the multivariate linear programming and regression analysis to solve the problem. Aerial refueling study help to make transport emergency drugs and submit it to the destination in the shortest time.First we proposed three sets of constraints, then we use Dichotomy to put forward a plan for the feasible refueling, and use five tankers to complete the transport plan. Joined the failure factors and meteorological factors, flying height, using regression analysis to establish the time and the linear relationship of various factors, using multivariate linear programming, put forward four groups of constraints and an objective function, the objective function is the total time. The purpose is to minimize the total time, uses genetic algorithm to solve the model. It is concluded that the seven tankers transport plan completed, and the main parameters of the algorithm is discussed and optimized, the superiority of the proposed algorithm, the results show that the method is feasible.

Keywords

Genetic algorithm; Linear programming; Dichotomy model; Aerial refueling.

1. Introduction

The storage quantity of each aircraft is limited, if we can't timely refueling it we will be tricky. Our research question is just like this, a rescue plane depends on the amount of oil itself is unable to lead the people in need of help safely. This is where the aerial refueling technologies to assist. Then how to arrange is the most reasonable, the problem that aerial refueling tanker technology are faced with, the results may lead to ... are the problems we must consider.

2. Restatement of the Problem

There was a small island in the hazards, we sent rescue aircrafts carrying supplies to support, and bring the casualties back to land. But the oil is not capable to support rescue aircraft to fly back to the land safety, then we need to send to rescue aircraft aerial refueling tanker, and tankers to upgrade, increase tankers for oil. We are now known, rescue aircraft flight back and forth and can accommodate the most bulk oil tanker, unit fuel consumption, in the first question, easy to send a few tankers can only make rescue aircraft safe return, after a simple calculation can obtain a feasible solution.

In the second question, we want to consider more complicated factors, such as speed, wind speed, pipe length, risk, etc., after comprehensive consideration of various factors, using the Genetic algorithm and Linear programming, we get a optimal scheme of dispatching tanker.

3. Assumptions and Justifications

1. Rescue aircrafts and tankers' speed, unit time and fuel consumption are the same and the singular.

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2. After the fuel tank filled with oil, carrying first-aid medicine aircraft fly at 680 nautical miles. Aerial refueling equipment installed plane maximum range is 745 nautical miles. Before the oil tank is zero , they can fly at a constant speed.

3. Rescue aircrafts can refuel tankers; tankers can also come on each other. They can do this only one in a time, also can at the same time for multiple planes refueling.

4. Assume that tankers and rescue aircrafts' performance are the same, and there is only one tank.

5. We don't discuss the plane circling in the air.

6. The plane vertical takeoff and vertical landing to the air, on the ground or time consuming in the air are negligible.

7. Because of the transportation task mostly in the stratosphere, ignore the weather factors.

4. Notations

All the variables and constants used in this paper are listed in Table 1.

Table 1. Symbol Table

Symbol	Defination	Units
k	The total number of the plane	frame
T_{yi0}	The rescue aircrafts' initial fuel	Kg
T_{yij}	The transport plane i needs oil in j	Kg
f_{yi}	Safety oil of transport aircraft	Kg
L_{yij}	Every flight segment of transport aircraft	nautical mile
T_{ti0}	The initial oil of tanker i	Kg
f_{ti}	Safety oil of tanker	Kg
C_{tij}	The tanker plane i gives oil in j	Kg
G_{ik}	The tanker i can give the oil k in available in the airspace	Kg
L_{ti}	Every period of one-way journey of tanker	nautical mile
Q_k	The minimum fuel required in airspace k	Kg

5. Model Overview

5.1. Model Introduced Dichotomy Model

According to the topic and calculating, we can easily get a rescue that aircrafts depend on itself can be finished half of their range. So we only need to consider rescue aircrafts' return stage.

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We assume the distance L, Lyij and Lti mean rescue aircrafts' each respective distance and tankers each one-way journey.

We assume that when the rescue oil quantity is zero, tanker can arrived rightly the rescue aircrafts' position, and rescue aircraft oil in time.

5.2. Problem Analysis

According to our rough calculations, rescue aircraft's oil is zero on the voyage home, then we sent a tanker to rescue aircraft oil.

Because we need not only ensure the smooth return of rescue aircraft, also made tankers are smooth return, we use a kind of algorithm, it is that when the tankers and rescue aircraft met, the tanker give a half of the rest of the oil to the rescue aircraft and half to itself, to ensure the tanker itself and the rescue aircraft can synchronously back, we call it Dichotomy.

And when tankers and rescue aircrafts in return journey, they can also experience that the tank of oil became zero. Because now the rescue aircraft and the first tanker's oil quantity are all zero, they all became the receive aircrafts. Then wo would send another two tankers, using the Dichotomy, then four aircrafts synchronously back. If the four planes are no oil at the same time when they are coming back, we also need to consider sending more tankers.

5.3. Model Build

So, we can draw transport planes' and tankers' formula, Transport plane:

$$(\sum_{i=1}^{k} T_{yij} - \quad f_{yi}) \quad 0.2 \geq L_{yij} \tag{1}$$

$$\sum_{i=1}^{k} G_{ik} \quad \geq Q_k (k \quad = 1,2,3 \quad \ldots k) \tag{2}$$

$$\left(\sum_{i=1}^{k} T_{ti0} - f_{ti} - C_{tij} \right) \Big/ 0.2 \geq 2\mathrm{L}_{\mathrm{ti}} \tag{3}$$

According to the results, we can get the result that send 5 tankers can make all of them return smoothly.

5.4. Results

According to the actual situation, we assume that the plane speed are 600 nautical miles per hour, and the origin is the conveyor's starting place, the rest of the tanker aircrafts taking off from the origin. Flight planning in the following table 2.

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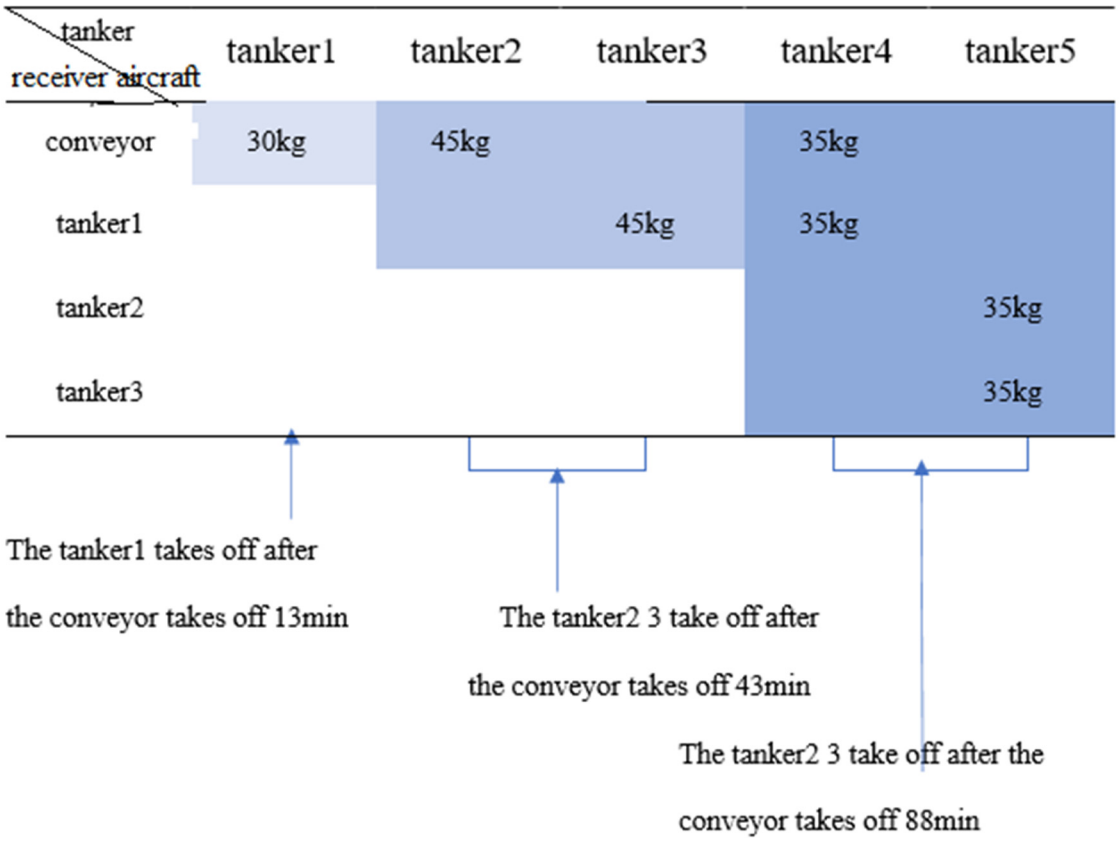
Table 2. The planes' arrangement



5.5. Model Description

1. Question assumptions

(1) Assuming only a plane failure at the same time.

(2) Assuming the speed only based on the altitude, resulting in flight time is affected.

(3) Assuming that if not failure, it is flying at a constant speed, the speed depends on the altitude.

(4) The aircraft malfunction when hovering in the air, but the process is not fuel, and it can repair, maintenance time is included in the total time.

2.Regression analysis

Regression analysis is on the basis of a large number of observation data, by using mathematical statistic method to establish the return of the relationship between the dependent variable and independent variable function expression. regression analysis is a statistical principle is used to describe the correlation between random variables is an important method.

Regression analysis can be used to determine the relationship between the variables and the total time used, regression using the best fitting line in the dependent variable (Y) and one or more independent variable (X)to establish a relationship.

Use an equation to represent it, that is, $Y=a+b\cdot X+e$, in which a for intercept, b said linear slope, e is the error term. This equation can be predicted according to the given variable to predict the value of the target variable.

3. Multivariate linear programming model

The basic model of multivariate linear programming is: a target function and the scope of variables in the objective function, using the number form combining ideas and mathematical knowledge, when we find out the independent variable is what, the objective function obtains the biggest solution, calculate the value of problem solution, using the linear programming ideas get the most value, clear thinking, visual image, easy to understand and master.

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Meteorological factors are of great significance to air flight. Meteorological factors (w) had obvious correlation with the aircraft speed and weather conditions can be divided into four grades respectively is good, nomal, serious, severe and extreme, with 1, 2, 3, 4, and the speed of the aircraft is inversely proportional to the level of meteorological. According to the regression analysis, w_j says the first j plane faced by meteorological conditions.

During the aircraft flight, the aircraft will failure occurs because of some factors, and the need to certain top ten time of maintenance, plane load, the greater the probability of failure is higher, with BT_j said the first j plane down time needed for maintenance.

Because of the influence of the climatic conditions, will affect the flight of the height (h), if the bad weather, the take-off low altitude, flight speed will slow down, in the process of take-off height will not only influence the departure time, so can also affect the flight speed.

With T_{hj} represents the first time needed for j aircraft take off, take off height is divided into four grades, from down to high alignment is 1, 2, 3, 4. According to the regression analysis respectively, time for take-off kT_{hj} aircraft at a rate of 1 / (w_j * H_{JZ}). S_j represents the one-way distance that the first j plane flight.

The objective function is:

$$\min T = (\sum_{i=1}^{k} 2s_j) \times (w_j \times h_j) + \sum B_{ij} + \sum_{j=1}^{k} T_{hj} \qquad \sum_{j=1}^{k} \tag{4}$$

The constraint is:

(1) aircraft maintenance within the scope of time value.

$$\beta_1 w_j \leq BTj \leq \beta_2 w_j (j = 1,2,...,k) \tag{5}$$

(2) take-off time constraints

$$k \leq kT_{hj} \leq 4k (j = 1,2,..., k) \tag{6}$$

(3) each flight distance is greater than two times of the target distance and target distance is less than k times.

$$6.5 \times 2 \leq \sum_{j=1}^{k} s_j \leq 6.5k \tag{7}$$

$$1 \leq w_j \leq 4 (j = 1,2,...,k) \tag{8}$$

$$1 \leq h_j \leq 4 (j = 1,2,...,k) \tag{9}$$

Refueling planning optimization model not only considers the tankers in the allocation of resources, but also for the allocation of resources allocation, again come on time constraints, is a complex combinatorial optimization problem, the genetic algorithm is feasible.

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4. Genetic Algorithm

Genetic algorithm is used to solve optimization search algorithm in computational mathematics, is a kind of evolutionary algorithms.

Evolutionary algorithm was originally borrowed some phenomenon in evolutionary biology and developed, these phenomena, including heredity, mutation, natural selection and hybridization, etc.

Genetic algorithm is usually implemented as a computer simulation.To a optimization problem, a certain number of candidate solutions (as individuals) abstract representations (called chromosomes) population for the better solution of evolution.

Traditionally, the solution using binary representation (i.e., the string of 0 s and 1 s), but can also be expressed in other methods. Evolution from completely random individual populations, generation after generation.

In each generation, the fitness of the whole population is evaluation, multiple individuals are randomly selected from the current population (based on their fitness), through natural selection and mutation to create new life population, the population became the current population in the next iteration of the algorithm.

5.6. Problem Analysis

1. The plane failure

In the process of flight, though transporting and refueling aircraft fault has certain unpredictability, based on data statistics and analysis of the existing literature, we can draw on a plane failure probability and the required maintenance time.

In this paper, on the basis of the aircraft fault predictable, and can be quantified. Moreover, when the plane failure occurs, the process of filling up are good breakdown maintenance after can still continue refueling.

In actual flight process, when a fault occurs that may many plane break at the same time. This article assumes that the fault only occurs in a plane. In the simulation experiment of breakdown as a result, the plane needs to determine three parameters:

(1) the hypothesis which a plane failure;

(2) when the plane down;

(3) how long does it take to aircraft maintenance.

Combined with the topic and the analysis of the existing literature, there was an aircraft aircraft overload failure probability is higher, and easily affect gas completion time.

To this end, each aircraft the probability of failure is:

$$p_j = \frac{w_i}{\cdots_p} \tag{10}$$

In this formula: p_j said the plane j the probability of failure; W_j said plane load; W said the total load of the all aircrafts. The greater the probability that the greater the chance of the failure of the aircraft.

The time of the failure of the aircraft is:

$$BT_j = [\alpha_1 W_j, \alpha_2 W_j] \tag{11}$$

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In this formula: 1, 2 for fault coefficient of value for the random number of intervals [0, 1]; BT_j said aircraft fault time, obey uniform distribution within the range.

When the fault coefficient values within the range of [0, 0.5], said before the refuelling mission in the half period of failure; Values in [0.5, 1], said in a refuelling mission during the second half of the failure.

The aircraft maintenance time after failure is:

$$RT_j = [\beta_1 W_j, \beta_2 W_j] \quad (12)$$

In this formula: 1, 2 for maintenance coefficient, the value of random Numbers for [0, 1] interval, RT_j to repair time, obey uniform distribution.

2. The chromosome encoding

Effective chromosome coding can avoid the chromosome repair mechanism effectively, improving the efficiency of the algorithm. Aerial refueling problem need to solve the selection and breakdown maintenance task two subproblems.

The existing literature of chromosome coding way to form a chromosome, a feasible solution of the aerial refueling problem, and when using genetic selection of fitness function, to join for aircraft fault condition into account. Choose the length of the chromosome cheer for all the planes on the number of tasks combined, according to each gene tanker and its order of task assignment.

A chromosome is an array of an array subscript said task number, array the serial number of the value of the said tankers. The chromosome [I] = j is the meaning of: the task I assigned to the node j. so in the process of programming operation can be very convenient for mutation, crossover operation without repair mechanisms, etc. To the first question is shown in feasible refueling planning as an example, such as the first question, as shown in the figure the actual number in addition to 7, the actual length of chromosomes 7 plane.

Suppose a chromosome to [0, 0,..., 1,0,0,0,..., 4,5,0,0,0,..., 2,3,0,0,0,...]is shown in figure 1, that is, the scheduling scheme of the tanker.35 in the chromosome for task corresponding values for the "4", said the optional 4 refuel aircraft in the tanker, the optional tanker set {1, 2, 3, 4, 5}, refueling aircraft for 4, 4.Task 30 genes that a value of 1, processing plane is 1. By analogy, the whole chromosome tanker is: the 1-4-5-2-3.

3. The population initialization

Population initialization process, the solution of the individuals in the initial population quality has great influence on the efficiency of algorithm. Initialization method is proposed based on the existing literature, global search and local search, make each refueling refueling mission between balance as far as possible. Both global search and local search, every time want to record all the aircraft load, as a base, as the basis of the current task to choose tanker.

They come on time, however, is not the same, global search in tanker choice after the completion of all tasks, records of jet fuel load data reset; Local search in tanker choice after the completion of each task, and reset all aircraft load records.

In the process of algorithm , to increase the population diversity, global search, local search and random search combination initialization method.

4. Crossover operation

The choice of the ways of crossover operation to the pros and cons of a new generation of individuals in the population quality and excellent information reserves have important role.

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Based on chromosome tankers task allocation according to the characteristics of the coding, aircraft choice of chromosome is carried out in accordance with the task order, the order between them could not be broken, so adopt the method of two-point crossover.

Randomly generated two intersection, two intersection interval of chromosome segment to exchange, it can maintain their position does not change with the order, and then for each chromosome, can better inherit the excellent characteristics of the parent individual.

5. Mutation

Mutation can enhance population diversity to prevent premature convergence. For aircraft choice chromosomes, adopt four kinds of variation method, namely each refuelling mission in the optional tanker concentrated random choose other replace the current selected refueling tanker aircraft, exchange, insert, and reverse, randomly select a mutation variation method.

6. Select operation

Select operation role is to make the high performance of the individual to a greater probability of survival, to avoid the loss of effective gene, maintain a constant population size, at the same time, to speed up the global convergence and improve the computational efficiency.

More commonly used methods have roulette, sorting, selection, seed selection and tournament selection. This article uses the roulette wheel selection method, also called selection method. The basic idea is: the probability of each individual is selected and its fitness is proportional to the size.

Specific operation is as follows:

(1) Calculate the groups the fitness of each individual f (I = 1, 2, ..., 20), 20 size for the colony;

(2) Calculate the probability of each individual is heredity to the next generation of the group;

$$P(x)_i = \frac{f(x_i)}{\sum_{j=1}^{N} f(x_j)} \tag{13}$$

(3) Calculate the cumulative probability of each individual;

q[i] called the accumulation of probability of chromosomes X[I] (I=1,2, …, n)

$$q_i = \sum_{j-1}^{i} P(x_j) \tag{14}$$

(4) In [0, 1] interval to produce a uniform distribution of pseudo-random number r;

(5) If r < q [1], select individual 1, otherwise, select individual k, makes: q [k-1] <r≤q [k];

(6) Repeat (4), (5) for 20 times.

5.7. Consepuence

For there can't be many planes fail at the same time, the failure probability based on the oil of load are given tankers, so every time the fault is different from simulation using MATLAB program.

The best arrangement we have solved is as follows.

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Table 3. The optimal aircraft scheduling

Receiver air / Transport air	Tanker 1	Tanker 2	Tanker 3	Tanker 4	Tanker 5	Tanker 6	Tanker 7
Tanker 1	30kg		45kg			35kg	
Tanker 2				45kg		35kg	
Tanker 3					15kg [1]	30kg	5kg [3]
Tanker 4					15kg [2]		20kg [3]
Tanker 5					15kg [2]		20kg [3]
							35kg [3]

But according to the actual problem of background, in order to ensure the transport task can complete smoothly, we based on the assumption model considering all the possible fault condition, making the plan in all possible failure cases, in the shortest possible time to complete transportation refueling mission, namely considering the aerial refueling every link of the possibility of failure, on the premise of ensure the overall success rate of optimization solutions.

6. Sensitivity Analysis

Genetic algorithm took the form of group search optimization, gradually to be near global optimal solution. Sensitivity analysis according to the principle of least squares iterative step by step and make the correction effect gradually close to the optimal solution. Genetic algorithm and sensitivity analysis to the test data are not required to complete the modal vibration mode, and in the case of adequate and accurate test data, the sensitivity analysis method, the final point of convergence and the global optimal solution of the genetic algorithm should be consistent, it provides the mix of the two methods.

At the same time, the genetic algorithm has good global search ability and sensitivity analysis method has the characteristics of fast simple, its mixing can complement each other, is meaningful for engineering application.

In this paper, considering the characteristics of genetic algorithm and sensitivity correction respectively, the sensitivity of the genetic algorithm, its biggest feature is on the basis of the original genetic algorithm increases the sensitivity correction operation, the operation can be seen in figure 1.

(1) whether genetic algebra requires sensitivity correction (fixed interval integer times), if it is, is for 2-4 operation.

(2) according to the revised probability random selected individuals ready to be revised.

(3) Of the selected individuals, by calculating the corresponding to the first- order sensitivity matrix, adjust the quantity is calculated for each variable, and then to a correction current idiotype.

(4) select the best individual in current generation and sensitivity correction (one or more times, if not specified otherwise, a correction is adopted) and the revised one body to another as save, and inserted into the next generation of selected sub populations, it is very important to reduce the computing time.

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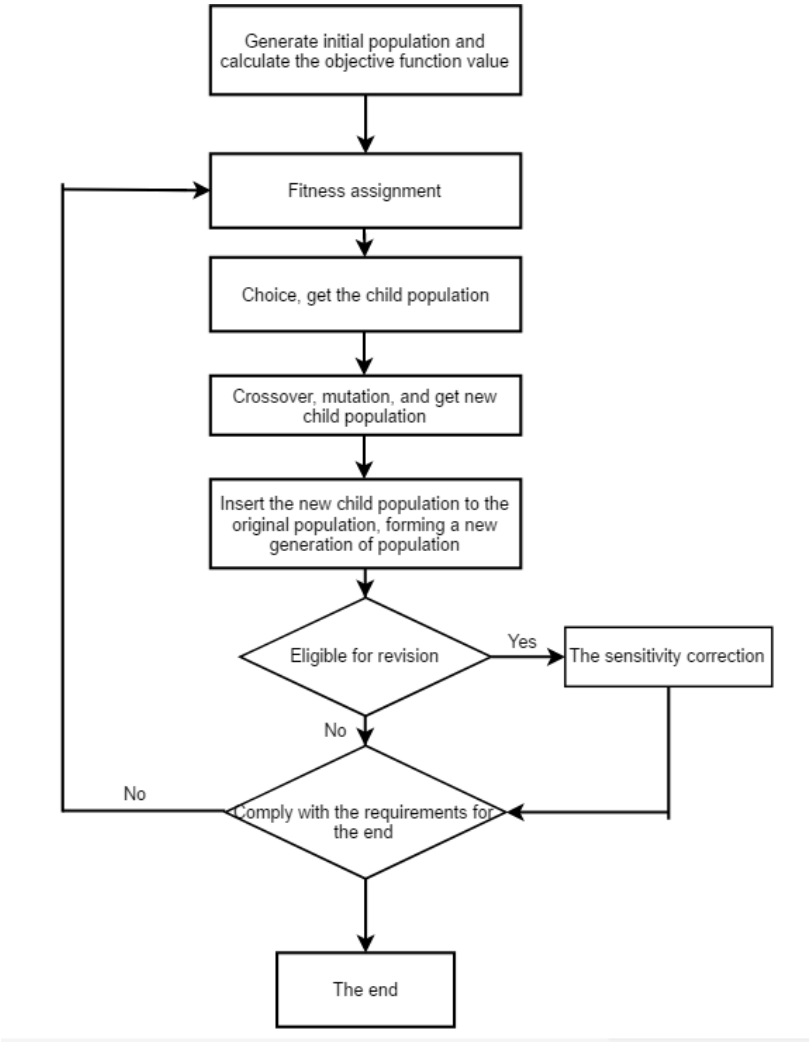

Figure 1. The genetic algorithm operation

The sensitivity of the main steps of genetic algorithm Sensitivity of genetic algorithm is designed to hope to be able to play to the role of the sensitivity correction brings to the genetic algorithm is the following:

(1) the structure of the original state point closer to the real solution, can also make the individual in the genetics algorithm has to evolve to the global optimal solution.

(2) when the individual has been fixed in a population of genetic algorithm in optimal point with close, can pass the sensitivity correction quickly converge to the global optimal point.

(3) sensitivity correction is equivalent to the original individual based on a certain range of the base for fine tuning, to provide more diverse sample population genetic algorithm, enhancing the optimization ability of genetic algorithm.

By changing the genetic parameter Settings: population size according to the problem size from 40 to 100, was 0.7 crossover probability, mutation probability is 0.1, the largest number of iterations is 100, termination conditions meet the number of iterations.

In order to be able to better reflect the stochastic malfunction of machine, the algorithm run 10 times in a row.

According to the results of our sensitivity analysis, in the 10 random failure probability, only two results didn't agree with the the optimal solution we had concluded.

As shown in the chart are as follows.

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Table 4. Sensitivity analysis 1

Tanker / Receiver air	Tanker 1	Tanker 2	Tanker 3	Tanker 4	Tanker 5	Tanker 6
Transport air	30kg	45kg			35kg	
Tanker 1			45kg		35kg	
Tanker 2					30kg	5kg[2]
Tanker 3				10kg[1]		25kg[2]
Tanker 4						35kg[2]

Table 5. Sensitivity analysis 2

Tanker / Receiver air	Tanker 1	Tanker 2	Tanker 3	Tanker 4	Tanker 5
Transport air	30kg	45kg		35kg	
Tanker 1			45kg	35kg	
Tanker 2				15kg [1]	20kg [2]
Tanker 3				15kg [1]	20kg [2]

For the first time, the sensitivity analysis 1 send tankers random failure probability of the first round is zero, the optimal scheduling aircraft is six.

For the second time, the sensitivity analysis 2 sent tankers random failure probability of the third round is zero is zero, then the optimal scheduling aircraft number is five.

Because we consider the failure factors, according to the results of sensitivity analysis, can get us through MATLAB calculated results of effective and after considering all kinds of fault factors, is the optimal results.

According to the table of contents, based on genetic algorithm is concluded that the scheme is feasible, adaptability and effectiveness of the proposed method was verified.

7. Strengths and Weaknesses

7.1. Strengths

1.Genetic algorithm uses iterative probability mechanism, randomness, when test task length, can be randomly assigned tasks, increase the possibilities.

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2.Multivariate linear programming has a unified algorithm, easy to calculate.

3.Asked the first (1) using the Dichotomy of can simply make assumptions, simplify the problem, facilitate after calculation.

4.Regression analysis can accurately measure the factors fitting degree of regression and correlation degree between high and low, improve the effect of prediction equations; Due to a variable in the regression analysis method is rarely influenced by individual factors, only to pay attention to the suitable range of the model. So, one factor regression analysis for the influence that there is a dependent variable, significantly more variable than the other factors are used. Multivariate regression analysis method is suitable for the actual programming, comprehensive influence by various factors.

7.2. Weaknesses

1.Because this article assumes that the plane failure occurred in a, of the failure of many sets of machines at the same time and situation and other uncertain factors need further study.

2.The poor local search ability of genetic algorithm, leading to the simple genetic algorithm is time-consuming, in the late evolutionary search efficiency is low. In the length of multiple tasks, requires a lot of time to search for the length of the accords with a condition, and prone to premature convergence problem.

3.Sometimes in regression analysis, choose what kind of factor and the factor what expression is a kind of speculation, this affects the unpredictable nature of some factors, such as judgment of weather factors, the influence degree is just speculation, there is no clear relationship, regression analysis, in some cases was limited.

4.For the accuracy of the data demand is too high, can only be planning problem of linear constraint, and the amount of calculation is too large. Have evolved by linear programming method of nonlinear programming method, and so on the follow-up, but increase the amount of calculation.

8. Conclusion

At first, this paper uses the binary model without considering the fault factor and other conditions, sending five tankers is calculated. After considering the plane failure could occur, as well as the meteorological factors will affect the aircraft flight.

Through calculating the probability of failure and the use of regression analysis to establish the linear relationship of various influence factors on the airplane flight time, using multivariate linear programming constraints is put forward, using genetic algorithm to solve the model, get the optimal number of plane frame for 7 tankers, sensitivity analysis, verified the feasibility of the scheme.

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