

Research Article

Research on Location Selection Strategy for Airlines Spare Parts Central Warehouse Based on METRIC

Rui Wang (), Yicong Qin (), and Hui Sun ()

College of Electronic Information and Automation, Civil Aviation University of China, Tianjin 300300, China

Correspondence should be addressed to Hui Sun; h-sun@cauc.edu.cn

Received 20 June 2021; Accepted 10 August 2021; Published 18 August 2021

Academic Editor: Yu-Ting Bai

Copyright © 2021 Rui Wang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

With the increased demands of airlines, it is important to study the location selection strategy for spare parts central warehouse in order to improve the allocation capacity of spare parts maintenance resources and reduce the operating costs of airlines. Based on the $M/M/s/\infty/\infty$ multiservice desk model and Multi-Echelon Technique for Recoverable Item Control (METRIC) theory, this paper proposes a spare parts supply strategy based on the spare parts pool network and establishes a location selection model for spare parts central warehouse. The particle swarm optimization (PSO) algorithm is used to iteratively optimize the location for spare parts central warehouse and adjust the location area of the central warehouse combining transportation facilities and geographical environment factors. Finally, the paper compares the operating results for multiple airlines in pooling and off-pooling states and verifies the effectiveness of the spare parts supply model and the advantages of cost control for airlines.

1. Introduction

The airlines spare parts are the key resources to ensure the normal operation of the airframes, on-board equipment, and ground support equipment [1]. According to the survey, the total spare parts inventory value for supporting the operations of all airlines in the global aviation market reaches US\$50 billion, accounting for 75% of airline inventory funds and 25% of working capital. However, most of the airlines spare parts are redundant in fact, and only 25% of the airlines spare parts are turnover in the industry [2, 3]. With the repeated COVID-19 epidemic and the fierce competition in the aviation market, cost control has become a top priority for airlines. Therefore, how to promote the spare parts pooling among airlines to achieve a win-win situation and to reduce inventory redundancy while meeting the requirements of spare parts guarantee rate are the key to the current airlines spare parts configuration management.

Airlines spare parts configuration management is an important way to realize the reasonable airlines spare parts inventory allocation, avoid shortage or waste of airlines spare parts, improve utilization rate of airlines spare parts, ensure reliability of dispatch, and reduce operating costs [4–6]. The development of this topic originates from the

Multi-Echelon Technique for Recoverable Item Control (METRIC) theory developed by the US RAND Corporation for the US Air Force. The METRIC theory is developed based on the establishment of a two-level (central warehouse level and maintenance base level) maintenance support system and optimization model. Assume that the repair capacity of repair shops is unlimited (the number of repaired equipment is unlimited), and the failure rate of parts is independent of the number of working parts [7]. Due to the long aging scrapping time of the turnover equipment in the real environment and the replacement problem of turnover parts is usually caused by the sudden failure and damage, so it is reasonable to ignore the impact of aging life [8]. This theory is widely used in the spare parts configuration management for complex equipment such as the OPUS software used by the European and American navies and air forces [9]. With the continuous development of METRIC theory, many scholars have carried out research on it from different perspectives. Aiming at the multilevel inventory problem of airlines spare parts, researchers start from the optimization problem of airlines spare parts guarantee supply inventory on the basis of the static Palm theorem and establish the METRIC model with the largest use efficiency of spare parts under the constraint of total costs [10]. On this basis,

reference [11] introduces the concept of virtual inventory and improves the METRIC model with the goal of the lowest overall cost of the spare parts inventory network. Reference [12] analyzes system with METRIC theory and introduces Lagrange factors to establish a multiconstraint dynamic configuration model of aviation materials and spare parts. Subsequently, depending upon the improved model of METRIC, dynamic METRIC (DYNA-METRIC), variant of METRIC (VARI-METRIC), and a mathematical model for METRIC (MOD-METRIC) are proposed. Among them, reference [13] proposes a DYNA-METRIC model that uses an unsteady composite Poisson distribution to simulate the dynamic characteristics of the spare parts supply environment with fewer restrictions on its application. Indeed, reference [14] conducted a study to show that an exponentially distributed interarrival time becomes apparent when the number of items in a system is more than ten. Then, it can solve a series of practical engineering problems. Reference [15] employs MOD-METRIC model to optimize the total cost constraint in the weapon equipment systems and obtains the number of spare parts at each level. Reference [16] analyzes the error of the expected shortage based on the negative binomial distribution and proposes the VARI-METRIC model. Subsequently, reference [17] proposes a METRIC-based model for the optimal allocation of spare stocking problems considering uncertain demand rate and limited repair capacity at the same time. The problem of supplying spare parts for a single fleet has been studied in references [18, 19]; however, inventory allocation issue with multiairlines has not been effectively analyzed. In the context of METRIC theory, the location of the central warehouse in the system cannot be ignored. In recent years, there have been many studies on the location selection [20-23]. Reference [24] develops a decision-made analysis of spare parts logistics in emergency, determines the distribution center of disaster relief goods, and deploys vehicles for relief distribution. On the basis of economic factors, reference [25] establishes optimization model of preventive maintenance and spare parts inventory to optimize maintenance decision and inventory level. References [26, 27] establish a location strategy considering factors such as economic benefits, infrastructure conditions, natural environment traffic location conditions, policies, and regulations. References [28-31] further discuss the location problem based on special factors. These factors are divided into the following six aspects: dynamic location based on uncertain demands, location based on supply chain competition perspective, multilevel logistics center planning and location selection study, service level-based location research, location selection combining logistics demand forecasting and distribution, and location selection considering the scale of logistics center construction. A lot of studies have also carried out on the selection of optimization algorithms for airlines spare parts configuration management. References [32, 33] use genetic algorithms to optimize the delay cost caused by unexpected failures and the overall cost of airlines spare parts occupation, furthermore, analyzing the effectiveness of the method through numerical examples. Reference [34] uses particle swarm optimization (PSO) algorithm to solve the

optimization problem of spare parts configuration which maximizes the airlines spare parts guarantee rate. Reference [35] builds a multiobjective optimization model and uses multiobjective ant-lion algorithm to achieve the Pareto dominance solution of airlines spare parts configuration optimization.

Although there are plenty of studies on airlines spare parts configuration management, the pooling of airlines spare parts among multiple airlines topic needs to be further focused on. The main contributions of the paper can be summarized as follows:

- (1) Based on METRIC theory, an airline spare parts supply strategy with the participation of multiple airlines is proposed from the airlines spare parts pooling perspective.
- (2) A model for the location selection of a spare parts central warehouse based on queuing theory is innovatively established to reduce the total operating cost for the multiple airlines.
- (3) A new PSO algorithm is developed to optimize the model along with good adaptability in terms of computational efficiency and high-dimensional model processing ability.

The rest of this paper is organized as follows. Section 2 describes the practical problems occurred in establishing a central warehouse for airlines spares parts, and model assumptions are placed. Section 3 proposes a location selection model for the central warehouse of airlines spare parts. Section 4 presents a PSO algorithm model based on dynamic decreasing inertia weight. Section 5 conducts simulations to verify the proposed model and algorithm in the previous sections. Finally, the conclusions are drawn in Section 6.

2. Problem Description

A number of airlines participate in coordinated deployment to realize the airlines spare parts pooling and establish an airlines spare parts central warehouse. Therefore, it is necessary to form an airlines spare parts demand network to meet all participating airlines demands. The airlines spare parts are uniformly dispatched and transported by the central warehouse, and the spare inventory of each maintenance base is reasonably allocated. If a maintenance base over the network has insufficient inventory, and Aircraft on Ground (AOG) occurred, emergency horizontal transfer among maintenance bases is carried out to minimize losses. In the end, with the goal of minimizing the total cost of airlines spare parts transportation, AOG loss, and spare parts storage cost, the location of the airlines spare parts central warehouse needs to be reasonably selected. To achieve a new pattern of alliance-based development of the airlines spare parts transfer network, the paper considers reducing ineffective competition among airlines, increasing airlines spare parts guaranteeing rate; reducing the inventory redundancy, thus reduces airline operating costs. The following assumptions are for the application consideration:

Assumption 1: the aging life of airlines spare parts is not considered in this paper for the time being due to the long aging scrapping time of the turnover airline spare parts in the real environment.

Assumption 2: the needs of airline spare parts always exist in each maintenance base, and the replacement demand obeys Poisson distribution. The total number of operating spare parts in the airlines spare parts pooling network is large enough; the exponential distribution can be used to approximate the interval arrival time distribution for failed items.

Assumption 3: the supply capacity of the spare parts for central warehouse is sufficient and there is no delay in dispatching. The rate of supply support obeys the negative exponential distribution.

Assumption 4: the transport rate and the unit cost are the constants for the same type of turnover parts.

Assumption 5: in case of emergency horizontal transfer, the AOG time is equal to the transit time between two maintenance bases, and no other incidents occur during the transit period.

3. Location Selection Modeling for Central Warehouse

3.1. Analysis of METRIC-Based Airlines Spare Parts Supply Strategy. The replacement of spare parts at each maintenance base is subject to the first come first service (FCFS) rule, and the spare parts are replenished by a combination of direct transfer from the central warehouse and emergency horizontal transfer. As shown in Figure 1, the model of airlines spare parts replacement operation and transfer for maintenance base *i*, *i* = 1, 2, ..., *n*, (hereafter abbreviated as base *i*).

In Figure 1, the dotted box represents the spare parts replacement demand waiting queue and spare parts inventory capacity of base *i*. For the spare parts replacement demand waiting queue, the priority of the replacement operations is given according to the FCFS rule. Then, replenish the spare parts inventory from the central warehouse *c* to base *i* by direct transfer. Within the direct transfer time t_i , if the queue length $k \le s$ (*k* is the total number of spare parts inventory) for base *i*, it is considered that the demand can be satisfied by the inventory of base *i* itself, and no emergency horizontal transfer is needed. If k > s within t_i , the demand of base *i* is not able to be satisfied by its own inventory, and the emergency horizontal transfer among bases is needed to support base *i* at this time.

The optimal order quantity formula, economic order quantity (EOQ), is used to determine the direct transfer strategy from central warehouse c to base i [36].

$$Q = \sqrt{\frac{2\Omega_i m_i}{\text{Storage}_c}},\tag{1}$$

where Q is the optimal order quantity of airlines spare parts; Ω_i is the annual demand for a certain type of repairable airlines spare parts for base *i*; m_i is the unit transportation cost for direct transfer of spare parts from central warehouse *c* to base *i*; *Storage*_c is the annual storage cost per unit of spare parts. The (s - 1, s) inventory strategy proposed in [37] is used because of the high storage cost and the low demand of the spare parts. Obviously, the optimal order quantity, *Q*, closes to 1. Subsequently, λ_i , the daily rate of spare parts replacement demand for base *i* as shown in equation (2), can be derived according to the average annual demand of repairable airlines spare parts model [38].

$$\lambda_i = \frac{T_{\rm FHi} \cdot K \cdot N}{365 \cdot T_{\rm MTBUR}},\tag{2}$$

where $T_{\text{FH}i}$ is the annual flight hours of a certain type of aircraft for base *i*; *K* is the average number of certain spare parts installed on the aircrafts; *N* is the fleet size of the aircraft; T_{MTBUR} is the mean time among unscheduled removals for the repairable spare parts. The rate of spare parts supply, μ_b from the central warehouse *c* to base *i* in direct transfer is shown in the following equation:

$$\mu_i = \frac{\overline{\nu}}{d_{ic}},\tag{3}$$

where d_{ic} is the distance from the central warehouse *c* to base *i*; $\overline{\nu}$ is the average transportation rate of this repairable spare parts. When the spare parts replacement demand of base *i* can be met by its own inventory, the spare parts inventory system at base *i* obeys the $M/M/s/\infty/\infty$ multiservice desk model. In this model, $\mu_{i1} = \mu_{i2} = \cdots = \mu_{ik} = \mu_i$. When there is a spare parts replacement demand of queue length *k* for base *i*, the overall spare parts supply rate of the system is $k\mu_i$, $k = 0, 1, 2, \ldots, s$. The supply intensity of one transfer from central warehouse *c* to base *i* is $\rho_i = \lambda_i/\mu_i$. The maximum supply intensity that the central warehouse *c* can provide to base *i* is $\rho_{is} = \lambda_i/s\mu_i$. To ensure the length of the queue for replacement parts not growing longer and longer, it should satisfy $\rho_{is} < 1$. Thus, when the demand at base *i* can be met by its own inventory, the cumulative replacement rate C_i (*k*) is

$$C_i(k) = \frac{(\lambda_i/\mu_i)^k}{k!}, \quad k = 0, 1, 2, \dots, s.$$
 (4)

Therefore, $P_i(k)$ is the probability of the spare parts to be replaced at base *i* with queue length *k*.

$$P_i(k) = C_i(k) \cdot P_i(0) = \frac{\rho_i^k}{k!} P_i(0), \quad k = 0, 1, 2, \dots, s, \quad (5)$$

where

$$P_i(0) = \left[\sum_{k=0}^{s-1} \frac{\rho_i^k}{k!} + \frac{\rho_i^s}{s! (1 - \rho_{is})}\right]^{-1}.$$
 (6)

In order to meet the airline's fill rate requirements and to avoid AOG in the event of spare parts replacement operations, the following equation should be met:

$$P_i(k \le s - 1) = \sum_{k=0}^{s-1} P_i(k) \ge 98\%.$$
(7)

When spare parts replacement demand cannot be met by its own inventory at base *i*, *i.e.*, the queue length $k \ge s$, AOG



FIGURE 1: Model of airlines spare parts replacement operation and transfer for base *i*.

will occur, and the exceeding portion is referred as the waiting queue. Thus, W_i (*s*, ρ_i), the probability that there exists a waiting queue in base *i*, obeys the Erlang waiting formula:

$$W_{i}(s,\rho_{i}) = \sum_{k=s}^{\infty} P_{i}(k) = \frac{\rho_{i}^{s}}{s!(1-\rho_{is})} P_{i}(0).$$
(8)

Since the input flow of spare parts demand in the system is Poisson flow, the waiting time for replacement of spare parts at base *i*, *T*, is a continuous random variable. It satisfies the nonnegative condition and obeys negative exponential distribution on t_i , so *T* has the Markov property. The probability of spare parts to be replaced at base *i* with $T \le t_i$ is

$$P_i(T \le t_i) = W_i(s, \rho_i) \cdot \left(1 - e^{-(s\mu_i - \lambda_i)t_i}\right), \quad t_i \ge 0.$$
(9)

Then, the cumulative replacement rate, C_i (k), in the waiting queue for base *i* is

$$C_i(k) = \frac{(\lambda_i/\mu_i)^s}{s!} \cdot \left(\frac{\lambda_i}{s\mu_i}\right)^{k-s} = \frac{(\lambda_i/\mu_i)^k}{s!s^{k-s}}, \quad k \ge s.$$
(10)

 $P_i(k)$ is the probability that there are k replacement demands for spare parts at base i which is shown below as well:

$$P_{i}(k) = C_{i}(k) \cdot P_{i}(0) = \frac{\rho_{i}^{k}}{s! s^{k-s}} P_{i}(0), \quad k \ge s.$$
(11)

Therefore, the average waiting queue length L_{iq} is

$$L_{iq} = \frac{W_i(s,\rho_i) \cdot \rho_{is}}{1 - \rho_{is}} = \sum_{k=s+1}^{\infty} (k-s) P_i(k) = \frac{\rho_i^s \cdot P_i(0)}{s!} \sum_{k=s+1}^{\infty} (k-s) \rho_{is}^{k-s}.$$
(12)

Emergency horizontal transfer also needs to be considered when there is a waiting queue at base *i*. The transit node *j* for emergency horizontal transfer depends on the transit time T_{ij} :

$$T_{ij} = \frac{d_{ij}}{\overline{\nu}},\tag{13}$$

where d_{ij} is the distance from base *i* to base *j*; \overline{v} is the average transport rate. In addition, the transportation cost of spare parts is

$$E_{ij} = a \cdot d_{ij},\tag{14}$$

where a is the transportation cost of spare parts per unit distance. In case of emergency horizontal transfer, the rate of spare parts supply from base j to base i is shown in the following equation:

$$\mu_{ij} = \frac{1}{T_{ij}}.$$
(15)

Subsequently, the spare parts supply strategy for base *i* is determined by the transit time T_{ij} , as shown in Figure 2.

When there is a shortage of spare parts at base *i* to apply for emergency horizontal transfer, the node *j* corresponding to min (T_{ii}) is selected as the supply base in preference. If base *j* is also out of stock, it is deferred to the next minimum value, etc. Since the central warehouse c has unlimited supply capacity, once $T_{ij} \ge T_{ic}$, spare parts are supplied from central warehouse *c* to base *i* by default, and other bases are not considered. According to Figure 2, it is assumed that the blue node represents the central warehouse c and the remaining four maintenance bases are identified as 1, 2, 3, and 4. The transit time from bases 2, 3, and 4 and central warehouse *c* to base 1 was ranked as $T_{12} < T_{13} < T_{1c} < T_{14}$. Bases 2-4 are divided into two different states according to the transit time, where the green node represents the emergency horizontal transfer node of base 1, and the red node means that the node cannot be used as the emergency horizontal transfer node of base 1. Therefore, if there is a shortage of spare parts at base 1, base 2 will make emergency horizontal transfer to base 1, and central warehouse c will make direct transfer to base 2 to replenish the inventory. Base 3 will provide horizontal transfer to base 1 only if base 1



FIGURE 2: Spare parts supply strategy.

generates an emergency horizontal transfer requirement and base 2 does not have inventory. Accordingly, the central warehouse *c* makes direct transfer to base 3 to replenish inventory. If bases 2 and 3 have no additional stocks simultaneously, the central warehouse *c* makes a direct transfer to base 1 to replenish the inventory. Since $T_{1c} < T_{14}$, base 4 does not need to provide emergency horizontal transfer to base 1. Therefore, bases 2 and 3 are called emergency horizontal transfer nodes for base 1. The priority ranking of the emergency horizontal transfer nodes for each base is shown in Table 1 according to the transfer time. Further, the source of the actual airlines spare parts replacement demand for base 1 is shown in Figure 3, where the green node represents base 1 as an emergency horizontal transfer node for bases 2, 3, and 4.

Since λ_i , i = 1, 2, ..., n, is independent of each other and obeys Poisson distribution,

$$\begin{aligned} X &\sim P(\lambda), \\ Y &\sim P(\mu). \end{aligned}$$
(16)

Then, there is

$$P\{X = x\} = \frac{\lambda^{x}}{x!}e^{-\lambda},$$

$$P\{Y = y\} = \frac{\mu^{y}}{y!}e^{-\mu},$$

$$P\{Z = z\} = P\{X + Y = z\} = \sum_{x=0}^{z} P\{X = x\} \cdot P\{Y = z - x\}$$

$$= \sum_{x=0}^{z} \left[e^{-\lambda}\frac{\lambda^{x}}{x!} \cdot e^{-\mu}\frac{\mu^{z-x}}{(z-x)!}\right]$$

$$= \frac{e^{-(\lambda+\mu)}}{z!}(\lambda + \mu)^{z}.$$
(17)

Any combination of variables that are independent of each other and obey the Poisson distribution still obey the Poisson distribution, that is, $Z \sim P(\lambda + \mu)$. Therefore, the modified combination variables are also applicable to this

queuing theory model. After the formation of the airlines spare parts pooling network, the actual spare parts replacement demand rate λ_{r1} is deduced in the following equation:



TABLE 1: The priority ranking of the emergency horizontal transfer nodes for each base.

Direct Transfer
 Horizontal Transfer

FIGURE 3: An example of the actual source of spare parts replacement demands for base 1.

$$\lambda_{r1} = \lambda_1 + P_2 (k \le s - 1) \cdot \lambda_2 + P_3 (k \le s - 1) \cdot \lambda_3 + [1 - P_3 (k \le s - 1)] \cdot P_4 (k \le s - 1) \cdot \lambda_4.$$
(18)

Therefore, the actual spare parts replacement demand rate λ_{ri} for base *i* is

$$\lambda_{ri} = \lambda_i + \sum_{\theta \in \{I\}} \left\{ P_{\theta} \left(k \le s - 1 \right) \cdot \lambda_{\theta} \cdot \prod_{\varepsilon \in \{H\}} \left[1 - P_{\varepsilon} \left(k \le s - 1 \right) \right] \right\},\tag{19}$$

where θ is the node index which regards base *i* as an emergency horizontal transfer node; {*I*} is the set of

emergency horizontal transfer nodes for θ ; ε is the node with higher priority than base *i* among all the emergency horizontal transfer nodes for θ ; {*H*} is the set of ε . As shown in Figure 4, the actual spare parts supply rate μ_{r1} for base 1 is a combination of μ_1 and the horizontal supply rate from the emergency horizontal transfer nodes (bases 2 and 3) of base 1.

Therefore, the actual expectation of supply rate of spare parts, $\overline{\mu}_{ri}$, for base *i* is

$$\overline{\mu}_{ri} = P_i (k \le s - 1) \mu_i + \left[1 - P_i (k \le s - 1) \right] \cdot \sum_{\tau \in \{V\}} \left\{ \prod_{\sigma \in \{Z\}} \left[1 - P_\sigma (k \le s - 1) \right] \right\} P_\tau (k \le s - 1) \mu_{i\tau},$$
(20)

where τ is the emergency horizontal transfer node of base *i*; $\{V\}$ is the set of τ ; σ is the base node with higher priority than τ among all the emergency horizontal transfer nodes of base *i*; $\{Z\}$ is the set of σ ; $\mu_{i\tau}$ denotes the supply rate of base τ to base *i* for airlines spare parts.

3.2. The Expected Cost of Pooling Strategy on Airlines Spare Parts. The expected cost of pooling strategy on airlines spare parts consists of the expected cost of spare parts

transfer, the expected cost of AOG loss, and the cost of airlines spare parts storage.

3.2.1. The Expected Cost of Spare Parts Transfer. The cost of spare parts transfer is composed of the direct transfer cost if the replacement demand can be met by its own inventory and the emergency horizontal transfer cost if maintenance base cannot be met by its own inventory. The expectation



FIGURE 4: An example of the actual source of spare parts supply for base 1.

cost function of spare parts transfer is shown in the following equation:

$$E_{t} = \sum_{i=1}^{n} \left\{ \sum_{k=1}^{s} ad_{ic}P_{i}(k) + \sum_{\tau \in \{V\}} ad_{i\tau}P_{i}(k) \left[1 - P_{i}(k \le s - 1) \right] P_{\tau}(k \le s - 1) \prod_{\sigma \in \{Z\}} \left[1 - P_{\sigma}(k \le s - 1) \right] \right\},$$
(21)

where d_{ic} is the distance from base *i* to base *c*; $d_{i\tau}$ is the distance from base *i* to base τ .

3.2.2. The Expected Cost of AOG Loss. The expected cost of AOG loss is shown in the following equation:.

$$E_{A} = \sum_{i=1}^{n} \sum_{j \in \{J\}} \frac{d_{ij}}{\overline{\nu}} (k-s) P_{i}(k) \left[1 - P_{i}(k \le s-1) \right] P_{j}(k \le s-1) \prod_{\Omega \in \{N\}} \left[1 - P_{\Omega}(k \le s-1) \right], \tag{22}$$

where $k \ge s$, {*J*} is the set of horizontal transfer nodes of base *i*; {*N*} is the set of base nodes with higher priority than base *j* among all emergency horizontal transfer nodes of base *i*.

3.2.3. The Storage Cost of Airlines Spare Parts. The storage cost of airlines spare parts consists of the storage cost of each node on the spare parts pooling network. The inventory capacity on each maintenance base will meet the spare parts fill rate higher than 98%. Therefore, the storage cost function of spare parts pooling is shown in the following equation:

$$E_s = \sum_{i=1}^n b \cdot s_i, \tag{23}$$

where b is the unit storage cost of the spare parts; s_i is the inventory of spare parts at base i.

Therefore, the total expected cost, E, of the airlines spare parts pooling network is shown in the following equation:

where E_t is the transfer cost of airlines spare parts per unit time consisting of both horizontal transfer costs and direct transfer costs; E_A is the AOG loss cost per unit time; D is the total time; E_s is the storage cost of airlines spare parts.

 $E = (E_t + E_A) \cdot D + E_s,$

4. A New PSO Algorithm Model Based on Dynamic Decreasing Inertia Weights

4.1. Particle Swarm Optimization Algorithm. In the location selection model for central warehouse of the airlines spare parts pooling network, the feasible domain of the original problem is the range where mainland China is located, and the feasible solution is expressed by the latitude and longitude coordinates of the range. The paper assumes that a group of "particles" in three-dimensional space is composed of longitude, latitude, and pooling expected cost in the feasible domain, and the particle is divided into its own experienced optimal position (p best) and global historical

(24)

optimal position (g best) according to the expected cost. During the (iter + 1)-th iteration, the velocity and position of the particles are updated by the following equations until the optimal solution is obtained:

$$v_{i}^{\text{iter}+1} = w \cdot v_{i}^{\text{iter}} + c_{1}r_{1}(p_{i}^{\text{iter}} - x_{i}^{\text{iter}}) + c_{2}r_{2}(p_{g}^{\text{iter}} - x_{i}^{\text{iter}}),$$

$$x_{i}^{\text{iter}+1} = x_{i}^{\text{iter}} + v_{i}^{\text{iter}+1},$$
(25)

where v_i^{iter} is the velocity of particle *i* for the iter-th iteration; P_i^{iter} is the *p* best of particle *i* for the iter-th iteration; P_g^{iter} is the *gbest* for the iter-th iteration; x_i^{iter} is the current position of particle *i* for the iter-th iteration; *w* is the inertia weight; c_1 , c_2 are learning factors; r_1 , r_2 are two mutually independent and uniformly distributed random numbers between (0, 1). In this paper, the formula for the inertia weight *w* dynamics model is shown as follows:

$$w^{\text{iter}+1} = w_s - \frac{w_s - w_e}{(\text{maxgen})^2} \text{iter}^2,$$
 (26)

where the maximum value of the inertia weight w_s is taken as 0.9. The minimum value of the inertia weight w_e is taken as 0.4. max gen is the total number of iterations. The inertia weight w takes values between (0.4, 0.9). The variation of w along with iter is plotted, as shown in Figure 5.

In the location selection model for central warehouse, the range of feasible domains is large, and it can be seen from Figure 5 that a larger w value and a smaller slope at the beginning of the iteration are beneficial for the particle to perform an adequate global search, while the w value becomes smaller and the slope becomes larger with the increase of the number of iterations, which is beneficial for the particle to converge quickly to the global optimum.

4.2. Flow of the Algorithm

Step 1: preset the scale of the particle swarm pop, the range of particle velocity, the feasible domain range of the particle, max *gen*, $w_s w_e$, c_1 , and c_2 .

Step 2: initialize particle swarm distribution, $X = \{x_1, x_2, ..., x_{pop}\}$; set the iter as 1.

Step 3: substitute the parameters λ_{ri} and $\overline{\mu}_{ri}$ into equations (7)–(10); update *p* best and *g* best.

Step 4: update w according to the number of iterations; update the velocity v and position x of each particle according to the velocity and position update formula.

Step 5: determine whether the number of iterations reaches max gen; if so, skip to Step 6; otherwise, let iter = iter + 1 and skip to Step 3.

Step 6: the output g best is the optimal location for the central warehouse, then end.

5. Simulation Analysis

The paper implements a repairable airlines spare parts pooling strategy of the A320 series fleet of *A*, *B*, *C*, *D*, *E*, and *F* airlines in order to carrying out the location selection for a



FIGURE 5: Inertia weight varies with the number of iterations.

central warehouse of spare parts pooling network. This paper uses linear regression to fit the relationship between the flight sortie, FS, and the flight hours, FH, of airlines' A320 series fleet. Then, the paper derives the parameter, $T_{\rm FH}$, based on the annual number of FS of the A320 series fleet of all bases for an airline. The fitted relationship is shown in Figure 6.

From the fitting results, it can be concluded that the *R*-square is 0.9557 and the Adj R-square is 0.9459. Therefore, there is a good second-order linear fitting relationship between FS and FH, which is shown in the following equation:

$$FH = -79.13 \cdot FS^2 + 3120 \cdot FS + 7.688 \times 10^4.$$
(27)

The historical database of airline $A \sim F$'s A320 series aircraft fleet at each maintenance base is summarized in the VariFlight website [39] and "Statistical Data on Civil Aviation of China 2019" [40]. The airline $A \sim F$'s FS at each base in China are screened, as shown in Table 2.

In airlines spare parts pooling network, λ_i for all maintenance bases of airlines A ~ F on the network is calculated according to equation (2), as shown in Table 3.

Further, μ_i and μ_{ij} are obtained according to equations (3), (13), and (15), which are substituted into equations (19) and (20) to calculate the value of λ_{ri} and $\overline{\mu}_{ri}$. Finally, the expectation costs are obtained by equations (21)–(24). The pooling expectation cost with the change of central warehouse location is plotted, as shown in Figure 7.

As seen in Figure 7, the lighter colors represent the higher pooling expectation cost when the location of the central warehouse c is chosen in that region. With the deepening of the color, the pooling expectation cost becomes lower. Therefore, it can be concluded that the existence of the optimal location within the feasible domain makes the lowest pooling expectation cost, and the more the spatial distance from the optimal location, the higher the corresponding pooling expectation cost. In turn, the pooling expectation cost model is iteratively searched for optimality according to the PSO algorithm process in Section 4.2, and the iterative results are shown in Figure 8.

Figure 8 shows that the algorithm has good convergence, and after 19 iterations of the algorithm, it can be found the lowest pooling expectation cost is with 131.4 million RMB. The final optimal location is shown with a star in Figure 9.



FIGURE 6: Linear regression between FS and FH.

TABLE 2: The FS of A320 series aircraft fleet at each base in China.

No.	City	FS
Airline A flight schedule	1	
1	Beijing	17924
2	Chengdu	28639
3	Dalian	17836
4	Fuzhou	1999
5	Guangzhou	18577
6	Guivang	2191
7	Harbin	6085
8	Haikou	7236
9	Hangzhou	2417
10	Hefei	492
11	Kunming	13429
12	Lhasa	2959
13	Lijiang	309
14	Mianyang	4359
15	Nanchang	3129
16	Nanjing	11177
17	Ningbo	4153
18	Qingdao	2519
19	Sanya	4078
20	Shanghai	12484
21	Shenzhen	6325
22	Shenyang	9478
23	Wuxi	388
24	Wuhan	1926
25	Xi'an	2882
26	Xishuangbanna	629
27	Yinchuan	2275
28	Changchun	1753
29	Changsha	3762
30	Zhengzhou	305
31	Chongqing	16656
Airline B flight schedule		
1	Beihai	833
2	Chengdu	2415
3	Dalian	1982
4	Guangzhou	7132
5	Guiyang	1917
6	Guilin	1061
7	Harbin	4426

TABLE 2: Continued.

Hanghou 379 Hobhoh 1333 10 Kumning 8350 11 Manyang 1231 12 Naming 3360 13 Sunya 44078 14 Shanphai 88152 15 Shenzhen 6425 16 Shanya 4078 17 Shijiazhuang 2707 19 Xian 4034 20 Kishuangbunna 839 21 Yinchuan 1365 22 Changchan 2103 Yinchuan 1365 224 Changgina 4014 Aritre C fight schedule 1 648 1 Beinai 648 2 Changgina 2075 24 Changgina 20358 25 Erdos 411 16 Frazbon 5598 77 Gungang 3535 13 Gungang 23505	No.	City	FS
9Höhbt13310Kumming133511Mianyang1235112Nanning1336613Sarya407814Shanghai8215215Shenzhan622516Shenzhang677017Shijizzhuang216618Urumchi701419Xian403820Kihuangbanna83921Yinchuan136522Changsha107523Changsha107524Changsha107525Ethai6482Reijing503583Chengdia2277324Dalian108035Etdos47115Etdos47115Etdos47116Fuzhou59897Gaangzhou235319Guilyang57319Guilyang435011Hatsin1639612Hangzhou1530513Hefei1530514Hohhot229915Jiana990816Kashi33377Shenzhang418319Hatsin1639613Hefei1530514Hohhot229915Jiang432316Kashi34317Kashi34317Kashi34318Hanghou15305 <td>8</td> <td>Hangzhou</td> <td>3759</td>	8	Hangzhou	3759
10Kunning885611Mianyang1225112Nanning336613Sanya407814Shanyani8215215Shenzhen632516Shenzhen632516Shenzhen701417Shijiazhang2015618Urunchi701420Kishuangbanna83921Yinchuan136522Changehan210323Changehan107524Chongging420125Grangaban227326Rejing5035831Chengghan10530327Chengghan2273528Guangzhou2235329Gualin999874Guangzhou2353535Guangzhou2353536Guangzhou2353537Guangzhou355138Guangzhou355139Gualin999811Habkin353532Guangaban343343Hefei15345344Hefei15345345Giangaban4329346Kunning44184347Kunning44184348Habkin343347Kunning44239348Giangaban4329349Kunning44239340Khuanghaina4363351Kinhuanghaina4373	9	Hohhot	1353
11 Manyang 1251 12 Nanning 3366 13 Sanya 4478 14 Shanghai 82152 15 Shenyang 6770 17 Shijazhung 2166 18 Urunchi 7014 19 Kian 4034 20 Kiahungbanna 839 21 Yinchuan 1365 22 Changsha 1075 24 Chongsha 1075 24 Chongsha 1075 24 Chongsha 1075 24 Changsha 1075 25 Changsha 1075 24 Changsha 1075 25 Changsha 1075 24 Changsha 1075 25 Fralos 4711 5 Fralos 4711 5 Fralos 4711 5 Fralos 4711 5 Fralos 4711 6 Gaungaloo 2535 7 Guangshon 3355 12 Harbin 1699 10 Harbin 1699 11 Halklou 3355	10	Kunming	8356
12 Nanning 3366 13 Sanya 4078 14 Shanghai 82152 15 Shenzhen 6225 16 Shenzhen 6225 17 Shijizzhuang 2166 18 Urumchi 7014 20 Kihuanghanna 839 21 Yinchuan 1365 22 Changsha 1075 24 Changsha 1075 25 Guingsha 1075 26 Reijing 5058 35 Guingshon 2273 41 Dalan 10503 25 Eiclos 4711 26 Fazhou 2353 29 Guingno 3515 12 Hangzhou 2353 13 Hefei 1534 14 Hohhot 2029 15 Hakou 343 <td>11</td> <td>Mianyang</td> <td>12351</td>	11	Mianyang	12351
13 Sanya 4078 14 Shanghai 42152 15 Shenzhen 6225 16 Shenzyang 6770 17 Shijizzhuang 21666 Urumchi 7014 7014 19 Yian 4031 20 Xishuangbanna 839 21 Yinchuan 1055 22 Changshan 2012 Arkine C flight schedule 1075 24 Chongsha 2012 Arkine C flight schedule 648 1 Belijing 50358 3 Chengdu 2273 5 Broko 4711 6 Furbou 598 7 Guangzhou 23535 8 Guijang 5515 9 Guilian 909 10 Harbin 1690 11 Haikou 3515 12 Hangehou 1505 13 Hefci 1534 14 Hohnbet 2029 15 Inan 960 16 Kashi 343 17 Kuming 4183 18 Liang 4323 2	12	Nanning	3366
14 Shanghai 82152 15 Shenzhen 62152 16 Shenzhen 62152 16 Shenzhen 62152 18 Urumchi 7014 20 Kishuangbanna 839 21 Yinchuan 1365 22 Changshan 1075 23 Changsha 1075 24 Chongsing 4201 Arline C flight schedule 1075 1 Belhai 648 2 Beijing 50358 3 Chengdu 2275 4 Dalian 10603 5 Etclos 4711 6 Fuzhou 5998 7 Guangzhou 2353 8 Guiyang 5751 9 Guilin 9998 10 Harbin 16596 11 Hagzhou 15305 12 Hangzhou 15305 13 Hefei 1534 14 Hohhot 2029 15 Jinan 9008 16 Kashi 343 17 Kunming 4183 18 Jhasa 1883 <	13	Sanya	4078
15 Shenzhen 6225 16 Shenzyang 6770 17 Shijiazhuang 21656 18 Urunchi 7014 19 Xian 4034 10 Xian 4034 20 Xiananghanna 839 21 Yinchuan 1365 22 Changsha 1075 24 Changsha 1075 25 Changsha 1075 24 Changsha 1075 25 Changsha 1075 26 Beijing 50358 3 Chengdu 2273 26 Beijing 50358 3 Chengdu 2573 3 Chengdu 2535 3 Guangzhou 2353 5 Erdos 4711 5 Erdos 4711 6 Fuzhou 5998 7 Guangzhou 2353 5 Erdos 4711 5 Guangzhou 2353 5 Guangzhou 2353 5 Guangzhou 3515 12 Haikou 1515 13 Haikou 3130	14	Shanghai	82152
16 Shenyang 6770 17 Shijazhuang 21656 18 Urunchi 7014 19 Xian 4034 20 Xibanagbanna 839 21 Yinchuan 21656 22 Changchun 2103 23 Changchun 2103 24 Chongring 4201 Arither C. Hight schedule 648 2 1 Beihing 648 2 Beijing 50358 3 Chengdu 22773 4 Dallan 10030 5 Frodos 4711 6 Fruzhou 598 7 Guangzhou 2353 9 Guilian 909 10 Harbin 16596 11 Haikou 3515 12 Hangzhou 15305 13 Hefei 1524 14 Habhot 2029 15 Jina	15	Shenzhen	6325
17 Shijiazhuang 21655 18 Urunchi 7014 19 Xian 4034 10 Xishuangbanna 839 21 Yinchuan 1365 22 Changsha 1075 23 Changsha 1075 24 Chongcing 4201 Arline C flight schedule 1075 1 Beining 6035 2 Changsha 1075 24 Chongcing 50358 3 Chengdu 2273 34 Chengdu 2273 54 Beijing 50358 55 Palian 10503 56 Fuzhou 598 70 Guiyang 5751 66 Fuzhou 595 79 Guilin 909 10 Harbin 16596 11 Hangzhou 15305 12 Hangzhou 15305 13 Hefei 15304 14 Hohot 2029 15 Jiaan 9608 16 Kashi 343 17 Kunnning 4131 184 Hohohot 2029	16	Shenyang	6770
18 Urumchi 7014 19 Xian 4034 20 Kishuangbanna 839 21 Yinchuan 1365 22 Changchun 2103 24 Chongqing 4201 Arime C Jight schedule 816 648 2 Beihini 648 2 Beihing 50358 3 Chengdu 22773 4 Dalian 10503 5 Chengdu 22773 4 Dalian 10503 5 Guangzhou 23553 6 Fuzhou 5998 0 Guiyang 5751 9 Guillin 909 10 Harbin 16596 11 Haikou 3515 12 Hangzhou 15305 13 Hefei 1224 14 Habhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunning 4118 18 Lhasa 1883 19 Lijiang 4323 20 Nanchang 21902 21 Nanjing 4233	17	Shijiazhuang	21656
19 Xian 4034 20 Xishangshana 839 21 Yinchuan 1365 22 Changsha 1075 23 Changsha 1075 24 Chongqing 4201 Artine C flight schedule 8eijing 50358 3 Chengdu 2273 34 Dalian 10503 5 Erdos 4711 6 Fuzhou 5998 7 Guangzhou 2353 8 Guiyang 5751 9 Guilin 9999 10 Harbin 16593 13 Hefei 15305 14 Hohhot 2035 15 Guiyang 5751 14 Hangzhou 15305 15 Jian 1531 12 Hangzhou 15305 13 Hefei 15304 14 Hohhot 2039 15 Jiang 433 16 Kashi 343 17 Kunming 4181 18 Ihasa 1188 19 Lijang 4332 20 Nanjingo 14239 <	18	Urumchi	7014
20 Kishuangbanna 889 21 Yinchuan 1365 22 Changchun 203 24 Chongging 4201 Aritne C flight schedule 648 2 Beijing 50358 24 Chengdu 22773 4 Dalian 1050 5 Frados 4711 6 Puzhou 5998 7 Guangzhou 2353 8 Guiyang 5751 9 Guilin 999 10 Harbin 16596 11 Hakou 3515 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Ihasa 1832 20 Nangba 14239 21 Nangba	19	Xi'an	4034
21 Yinchuan 1365 22 Changsha 1075 23 Changsha 1075 24 Chongsing 4201 Airline C flight schedule 8 648 1 Beihai 648 2 Beijing 50358 3 Chengdu 22773 5 Erclos 4711 6 Fuzhou 5998 7 Guangzhou 2553 8 Guiyang 5751 9 Guilin 909 10 Harbin 16596 11 Haikou 3515 12 Hangzhou 15303 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kumming 41181 18 Lhasa 1483 19 Lijang 4332 20 Nanjing 4828 21 Nanjing 4828 22 Shenzhen 2099 23 Guigdao 11306 24 Sanya 4078 25 Shanghai 117590	20	Xishuangbanna	839
22 Changchun 2103 23 Changchun 1075 24 Chongqing 4201 Arine C flight schedule 648 2 Beijing 50358 3 Chengdu 22773 4 Dalian 10503 5 Erdos 4711 6 Fuzhou 5998 7 Guargzhou 2353 8 Guiyang 5731 9 Guilin 909 10 Harbin 16503 11 Haikou 3515 12 Hangzhou 15305 13 Hefei 15305 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 4118 18 Lhasa 1835 20 Narchang 21902 21 Narjing 4239 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4074 30 Wuxian 2499 25 Shanghai 117590 26 Shenyang 6319 27	21	Yinchuan	1365
23 Changsha 1075 24 Chongqing 4201 Airline C flight schedule 648 1 Beihai 648 2 Beijing 50358 3 Chengdu 22773 4 Dallan 10503 5 Erdos 4711 6 Fuzkou 5988 7 Guangzhou 23553 8 Guiyang 5751 9 Guilin 909 10 Harbin 16596 11 Haikou 3515 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Lhasa 1832 20 Nanjing 4332 21 Nanjing 4323 22 Shanghai 117590 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 2396 27 Shenzhen 2396 28 Wenzhou 9870 29	22	Changchun	2103
24 Chöngging 4201 Arbine Clight schedule 648 648 2 Beijing 50358 3 Chengdu 22773 4 Dalian 10503 5 Erdos 4711 6 Fuzhou 5998 7 Guangzhou 23553 8 Guiyang 5751 9 Guilin 909 10 Harbin 16596 11 Haikou 3515 12 Hangzhou 15305 13 Hefei 15205 14 Hohbot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 4183 18 Lhasa 1883 19 Lijiang 4332 20 Nanjing 48283 212 Nanjing 4283 213 Qingdao 11356 214 Sanya	23	Changsha	10/5
Arme Cyngn scheduc 448 1 Beihai 648 2 Bcijing 50358 3 Chengdu 22773 4 Dalian 10503 5 Erdos 4711 6 Fuzhou 5998 7 Guangzhou 23553 8 Guiyang 5751 9 Guilin 909 10 Harbin 16596 11 Hangzhou 15305 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 4188 18 Lijang 4322 0 Nanghaj 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenyang 6319 27 Shenyang 6319		Chongqing	4201
number 1000000000000000000000000000000000000	1	Beihai	648
3 Chengdu 2273 4 Dalian 10503 5 Erdos 4711 6 Fuzhou 5998 7 Guangzhou 23553 8 Guiyang 5751 9 Guilin 909 10 Harbin 16596 11 Hangzhou 3515 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 4283 22 Ningbo 14239 23 Qingdao 11366 24 Sanya 4078 25 Shanghai 117590 26 Shanghai 12599 27 Shenyan 6319 28 Wuxin 18473 31 Wuxin 18473 32 Wuxin 2056 33 Xishuangbanna 2957 34 <td>2</td> <td>Beijing</td> <td>50358</td>	2	Beijing	50358
4 Dalian 10503 5 Erdos 4711 6 Fuzhou 5998 7 Guangzhou 23533 8 Guiyang 5751 9 Guilin 909 10 Harbin 16596 11 Harbin 1555 12 Hangzhou 15305 13 Hefei 1229 14 Hohhot 229 15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Lhasa 1883 19 Lijiang 4322 20 Nanchang 21902 21 Nanging 48283 22 Nanging 48283 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Wenzhou 9870 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wukan 2696 32 Wuhan 2696 33 Wuhan 2696 34 Wuhan <td>3</td> <td>Chengdu</td> <td>22773</td>	3	Chengdu	22773
5Erdos47116Fuzhou59987Guangzhou25538Guiyang57519Guilin90910Harbin1659611Hakou351512Hangzhou1530513Hefei1524414Hohhot202915Jinan960816Kashi34317Kuming4118118Lhasa188319Lhasa1833220Nanchang2190221Nanghaji4423923Qingdao1133624Shanghai11759025Shanghai11759026Shanghai11759027Shanghai11759028Wuxi847030Wuxi1847331Wuxi1847332Yinchuan269633Xishuangbanna293734Yulin326535Yulin326536Zhangjajie106737Changchun245438Changsha1316839Zhangjajie136639Zhangjajie136639Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316630Changsha13166 <td< td=""><td>4</td><td>Dalian</td><td>10503</td></td<>	4	Dalian	10503
6Fuzhou59987Guangzhou235318Guijang57519Guilin90910Harbin1659611Haikou351512Hangzhou1530513Hefei1524414Hohhot202915Jinan960816Kashi34317Kumming4118118Lhasa188319Lijiang433220Nanchang2190221Shanghai11336624Sanya407825Shanghai11759026Shenzhen229927Shenzhen229928Wenzhou987029Urumchi701430Wukan266633Xishanghana297534Yinchaa1205635Yulin326536Zhangjiaje106737Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha1316839Changsha13168	5	Erdos	4711
7Guangzhou23538Guyang57519Guilin90910Harbin1659611Haikou351512Hangzhou1530513Hefei1524414Hohhot202915Jinan960816Kashi34317Kumming4118118Lhasa188319Lhasa183220Nanchang2190221Nanjing4828323Qingdao1133624Shanghai11759025Shanghai11759026Shenyang631928Wenzhou97029Urunchi701430Wuxi1847331Wukan25635Yinchuan25636Zhangjiaje106737Changshana23734Yinchuan205635Yulin326536Changshana1316839Changshana23734Changshana1316839Changshana1316839Changshana1316839Changshana1316839Changshana1316839Changshana1316839Changshana1316839Changshana1316839Changshana1316839Changshana1316839Changshana <t< td=""><td>6</td><td>Fuzhou</td><td>5998</td></t<>	6	Fuzhou	5998
8 Guiyang 5751 9 Guilin 909 10 Harbin 16596 11 Hakou 3515 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kumning 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nangbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 2299 27 Shenzhen 2299 28 Wenzhou 9870 29 Urumchi 7014 30 Wukan 266 32 Xianugbanna 2937 33 Wukan 2696 34 Wukan 2696 35 Yuin 3265 36 Yuin 3265 36 Zhangjiajie 1067 37 Changghai 13168 38	7	Guangzhou	23553
9 Guiln 909 10 Harbin 16596 11 Haikou 3515 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunning 41181 18 Lhasa 1883 19 Ljiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 1136 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenzhen 22999 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuxi 1473 32 Xishuagbanna 2997 34 Yuin 3265 35 Yuin 3265 36 Zhangiajie 1067 37 Changchun 4254 38 Changsha 13168 39	8	Guiyang	5751
10 Harbin 16596 11 Haikou 3515 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunning 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shanya 4873 31 Wunan 2696 32 Wunan 2696 33 Xishuangbanna 2937 34 Wuhan 2696 35 Yinchuan 2056 36 Zhangiajie 1067 37 Changkana 2337 34 Yinchuan 2056 35 Yulin 3265 36 Zhangiajie 1067 37 Changshaa 13168 38 Changshaa 13168 <	9	Guilin	909
11 Haikou 3515 12 Hangzhou 15305 13 Hefei 15244 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunning 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Nanchang 21902 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenzhen 22999 27 Shenzhen 2399 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuxiangbanna 2696 32 Xianugbanna 2696 33 Xishuangbanna 2697 34 Yinchuan 12056 35 Yulin 3265 36 Zhangiajie 1067 37 Changchun 2454 38 Changsha 13168 <td>10</td> <td>Harbin</td> <td>16596</td>	10	Harbin	16596
12 Hangzhou 15305 13 Hefei 15404 14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 4833 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenzhen 22999 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wukan 2696 32 Xishuangbanna 2937 34 Yinchuan 2056 35 Yuin 3265 36 Zhangiajie 1067 37 Changsha 13168 39 Zhengzhou 2454 38 Changsha 13168 39 Zhengzhou 30168	11	Haikou	3515
13 Hefei 15244 14 Hohtot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 17590 26 Shenzhen 2299 27 Shenzhen 2299 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wukan 2696 32 Xishuangbanna 2937 34 Yinchuan 2696 35 Xishuangbanna 2937 34 Yinchuan 2056 35 Yinchuan 2057 36 Zhangjiajie 1067 37 Changsha 13168 39 Zhengzhou 2454 38 Changsha 13168 39 Zhengzhou 2454	12	Hangzhou	15305
14 Hohhot 2029 15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjajie 1067 37 Changsha 13168 38 Changsha 13168 39 Zhengsha 3168 30 Zhengsha 13168 31 Kinangbanna 3265 32 Yinchuan 3265 34 Changsha 13168	13	Hefei	15244
15 Jinan 9608 16 Kashi 343 17 Kunming 41181 18 Lhasa 1883 19 Ljiang 4332 20 Nanjing 42833 21 Nanjing 42833 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenzhen 22999 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjaje 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 30 Zhengzhou 5032 340 Changsha 13168 39 Zhengzhou 5032 30 Zhengzhou 5032 31 Changshau 13168	14	Hohhot	2029
16 Kashi 343 17 Kunming 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wukan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Yuhan 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changchun 2454 39 Zhengzhou 5032 40 Chongging 13168	15	Jinan	9608
17 Kunming 41181 18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenzhen 22999 27 Shenzhen 22999 28 Wenzhou 9870 29 Urumchi 7014 30 Wusi 18473 31 Wusan 2696 32 Xishangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	16	Kashi	343
18 Lhasa 1883 19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changchun 2454 39 Zhengzhou 5032 40 Chongging 18606	17	Kunming	41181
19 Lijiang 4332 20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wukan 2696 32 Xishuagbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changchun 2454 39 Zhengzhou 5032 40 Chongqing 18606	18	Lhasa	1883
20 Nanchang 21902 21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenzhen 22999 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xishungbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changchun 2454 39 Zhengzhou 5032 40 Chongqing 18606	19	Lijiang	4332
21 Nanjing 48283 22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuxia 2696 32 Xian 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changsha 3168 39 Zhengzhou 5032 40 Chongqing 18606	20	Nanchang	21902
22 Ningbo 14239 23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wukan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	21	Nanjing	48283
23 Qingdao 11336 24 Sanya 4078 25 Shanghai 117590 26 Shenzhen 22999 27 Shenzyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changchun 2454 39 Zhengzhou 5032 40 Chongqing 18606	22	Ningbo	14239
24 Sanya 40/8 25 Shanghai 117590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wukan 2696 32 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	23	Qingdao	11336
25 Shangnal 11/590 26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wukan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Quin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	24	Sanya	40/8
26 Shenzhen 22999 27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	25	Shanghai Shanghan	22000
27 Shenyang 6319 28 Wenzhou 9870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	20	Shenznen	22999
28 Weizhou 5870 29 Urumchi 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	27	Wanzhou	0319
29 7014 30 Wuxi 18473 31 Wuhan 2696 32 Xi'an 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	28	Urumchi	9870 7014
30 10473 31 Wuhan 32 Xi'an 33 Xishuangbanna 34 Yinchuan 35 Yulin 36 Zhangjiajie 37 Changchun 38 Changsha 39 Zhengzhou 40 Chongqing	30	Wuxi	18473
32 Xi'an 60516 33 Xishuangbanna 2937 34 Yinchuan 12056 35 Yulin 3265 36 Zhangjiajie 1067 37 Changchun 2454 38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	31	Wuhan	2696
33Xishuangbanna293734Yinchuan1205635Yulin326536Zhangjiajie106737Changchun245438Changsha1316839Zhengzhou503240Chongqing18606	32	Xi'an	60516
34Yinchuan200735Yinchuan1205636Yulin326536Zhangjiajie106737Changchun245438Changsha1316839Zhengzhou503240Chongqing18606	33	Xishijanghanna	2937
35Yulin326536Zhangjiajie106737Changchun245438Changsha1316839Zhengzhou503240Chongqing18606	34	Yinchuan	12056
36Zhangjiajie106737Changchun245438Changsha1316839Zhengzhou503240Chongqing18606	35	Yulin	3265
37Changchun245438Changsha1316839Zhengzhou503240Chongqing18606	36	Zhangijajje	1067
38 Changsha 13168 39 Zhengzhou 5032 40 Chongqing 18606	37	Changchun	2454
39 Zhengzhou 5032 40 Chongqing 18606	38	Changsha	13168
40 Chongqing 18606	39	Zhengzhou	5032
	40	Chongqing	18606

Attline D flight schedult Reijing 0452 2 Chengdu 4286 2 Dalan 1387 4 Giungzhou 6469 5 Guiyang 7688 6 Guilin 1137 7 Harbin 6451 8 Haikou 2243 9 Hangshou 2213 10 Kumming 6457 11 Lhasa 6994 12 Lijiang 1238 13 Manyang 9445 14 Nanjing 3129 15 Qingdao 8817 16 Shanghai 1503 20 Wenzhon 806 21 Waia 904 22 Waia 904 23 Wenzhon 1530 24 Waia 904 25 Yulin 1534 26 Zhanginji 457 27 Changhan 1	No.	City	FS
b. b	Airline D flight schedule	- 7	
2 Chengån 42780 3 Dalian 1387 4 Guaigapbu 6489 5 Guilan 1515 7 Harbin 6454 8 Haibou 2894 9 Hangzhou 21213 101 Kumming 667 121 Lijang 1213 101 Kumming 6674 121 Lijang 1213 121 Lijang 1213 123 Manyang 9145 134 Nanjing 3129 154 Qingdao 6319 154 Shoropang 6319 154 Wuxia 904 152 Wuxia 904 152 Yunin 155 154 Wuxia 904 152 Yunin 155 153 Changthan 1841 154 Yunin 155 154 Yunin 155	1	Beijing	40542
3 Dalan 1387 54 Guangzhou 6469 56 Guilan 1515 7 Harbin 6469 7 Harbin 6461 9 Hangzhou 2121 10 Kamming 6267 11 Lhasa 6941 12 Lijang 1238 13 Mianyang 9445 14 Nanjing 3129 15 Qangdao 6817 16 Shanghai 1503 17 Shenyang 619 18 Shenyang 619 19 Tanjin 2300 21 Wuai 904 22 Wuai 904 23 Wuai 904 24 Wuai 904 25 Yulia 155 26 Yulia 158 27 Changsha 1840 28 Changsha 1840 29 Zhonghai 945 20 Changsha 1840 23 Changsha 1840 24 Winan 158 25 Zhonghai 94640 26 Changghai<	2	Chengdu	42786
4 Gaugang 6460 5 Guyang 7688 6 Guiln 1515 7 Harbin 6454 8 Halsou 2894 9 Hangzhou 21213 10 Kumming 667 11 Lhasa 6944 12 Ljiang 3129 14 Nanjing 3129 15 Qingdao 8817 16 Shanghai 1503 17 Shenzhen 21074 18 Shenzhen 3200 20 Wenzhou 8636 21 Wuban 16177 22 Wuban 16177 23 Xi'an 1198 24 Yinchuan 5346 25 Yulin 155 26 Zhangibajie 457 27 Changchan 1840 28 Changchan 255 20 Deleinga 664014 </td <td>3</td> <td>Dalian</td> <td>1387</td>	3	Dalian	1387
b Guilin (135) 7 Harbin (414) 7 Harbin (414) 9 Harbin (212) 9 Harbin (213) 9 Harbin (224) 11 Lhasa (64) 12 Lijang (123) 13 Manyang 9445 14 Natjing 3129 15 Qingdao 8817 16 Shanghai (153)3 17 Orgdao 8817 18 Shenyang (319) 19 Tanjin 2300 20 Wuxi 904 21 Wuxi 904 22 Wuhan (16)77 23 Xi'an 1980 24 Yukin 153 25 Yulin 153 26 Zhangjiajie 457 27 Changsha 1840 28 Changsha 1841 </td <td>4</td> <td>Guangzhou</td> <td>6469</td>	4	Guangzhou	6469
	5	Guilin	/008
s Halon 2294 9 Hangzhou 2213 10 Kunning 6267 11 Lhiana 6594 12 Lijiang 913 13 Mianyang 9415 14 Nanjing 3125 15 Qingdao 8877 16 Shanghai 1530 17 Shenzhan 12074 18 Shenzhan 2300 20 Wuxi 9041 21 Wuxi 9042 22 Wuxi 9041 23 Xi'an 11882 24 Wuxi 9041 25 Yulin 1557 26 Zhanginait 457 27 Changsha 1880 28 Changsha 1880 29 Zhengzhau 1985 20 Zhengzhau 1985 21 Wuhan 1557 25 Yulin 155 26 Zhanginait 1880 29 Zhengzhau 1880 29 Zhengzhau 1880 29 Zhengzhau 1984 20 Chengghu 2526 2	7	Harbin	6454
9 Hangzhou 213 10 Kumning 687 11 Ihasa 6994 12 Ijijng 128 13 Mianyang 9445 14 Naning 313 15 Qangdao 8817 16 Shanghai 1303 17 Shanghai 1303 18 Shenzhen 1204 19 Tanjin 230 20 Wenzhou 8636 21 Wukai 904 22 Wuhan 16177 23 Xi'an 1198 24 Yinchuan 536 25 Yulin 155 26 Zhangjiajic 457 27 Changsha 1881 29 Zhengzhou 1842 21 Wukai 944 23 Zhengzhou 1852 24 Peljing 64014 25 Yulin 155 26 Gaugzhou 7406 27 Changzhou 252 <i>Aitne E fight schedule</i> 195 2 Beling 64014 20 Changzhou 7406 21	8	Haikou	2894
10Kumming.426711Lhas.699412Ljiang.123813Mianyang.944514Nanjing.312915Ojngdao.881716Shanghai.1530317Sherohen.1207418Sherohen.220020Weahou863621Wuban1617723Xi'an.198624Wuban1617725Yulin153626Yulin153627Changchan.188028Zhengthajie45729Zhengthajie45720Changchan.188025Yulin15526Zhengthajie45727Changchan.188028Chengqing.5252Arline F. flight schedule19452Beijing.6401424Dalian2814125Fuzhon25226Guagzhou727870Gaugzhou253611Habhat253612Jiana.25513Korla205514Habhat253615Lhasa125514Korla205515Lhasa25514Korla205615Lhasa25515Lhasa25516Lhasa25517Mianyang306618Nanc	9	Hangzhou	21213
11Lhasa(6994)12Lijiang1238)13Mianyang9445)14Naniing132915Qingdao881716Shanghai1530317Shenzhen1207418Shenzhen230919Tazjin230020Wenzhou863621Wuxi90422Wuhan1197823Xian1198824Yinchuan534625Yulin15526Zhangiajie47727Changsha188028Changsha188129Zhengzhou792830Chengchun184024Paina2322Artine E fight schedule19451Belnai19452Reijng6401434Chengchun28504Dalian28515Fuzihou25706Gauragzhou748067Gauragzhou235612Jinan864713Korla205514Kunning195915Lhasa125516Ljijang314717Mianyang506618Nanijng205114Korla205515Lhasa125516Ljijang314627Korla205518Nanjing2011820Naning <td>10</td> <td>Kunming</td> <td>6267</td>	10	Kunming	6267
12 Ljiang 123 13 Manyang 9445 14 Nanjing 3129 15 Qingdao 8817 16 Shanghai 15303 17 Shenyang 6319 18 Shenyang 6319 19 Tanjin 2309 20 Wenzhou 8636 21 Wuxi 904 22 Wuhan 16177 23 Xian 11988 24 Yuchuan 5346 25 Yulin 155 26 Zhangjiajie 457 27 Changchun 1840 28 Changchun 1841 29 Zhengzhou 7282 30 Changchun 1841 29 Zhengzhou 7282 <i>Arline E flight schedule</i> 1945 1 Beiling 64014 31 Chengdu 2570 20 Zhengzhou 24814 5 Fuzhou 2570 34 Changchun 1945 35 Fuzhou 2570 36 Guangzhou 74806 37 Guangzhou 74806	11	Lhasa	6994
13 Manyang 9445 14 Nanying 3129 15 Qingdao 8817 16 Shanghai 15303 17 Shanghai 2031 18 Shenzhen 12074 19 Tazjin 2300 20 Wenzhou 8636 21 Wuxi 904 22 Wukan 16177 23 Xian 11988 24 Yunchuan 5346 25 Yulin 155 26 Zhangjajie 457 27 Changchun 1840 28 Changchan 1881 29 Zbengzhou 7928 20 Chongqhan 2522 Arline E flight schedule 1945 2 Beijing 64014 2 Beijing 64014 2 Beijing 3834 2 Beijing 3834 2 Beijing 3834 3 Gaugarghou 74806 7 Guyang 3834 9 Haikou 1157 10 Haghou 2350 111 Hohbot 2350 <t< td=""><td>12</td><td>Lijiang</td><td>1238</td></t<>	12	Lijiang	1238
14 Nanjing 5129 15 Qingdaqo 8817 16 Shanghai 15303 16 Shanghai 15303 17 Shenzhen 12074 18 Shenzhen 12074 18 Shenzhen 2300 20 Wenzhou 8636 21 Wuban 16177 22 Wuban 16178 23 Yian 1198 24 Yuhan 16177 25 Yuhan 1617 26 Zhangjajie 447 27 Changchun 1840 28 Zhangjajie 447 29 Zhengjahou 7282 Arline E flight schedule 1881 2522 Arline E flight schedule 1841 1945 2 Parado 24141 2570 4 Dalian 28141 5 5 Fuzhou 23788 9 Harboin	13	Mianyang	9445
12 Qurgado 361.7 16 Shanghai 15303 17 Shenzhen 12074 18 Shenzhen 2300 19 Tianjin 2300 20 Wenzhou 8636 21 Wuxi 904 22 Wuxi 904 23 Xi'an 11988 24 Yinchuan 5346 25 Yulin 155 26 Zhangjiajie 457 27 Changchun 1840 28 Changsha 1881 29 Zhengzhou 7928 30 Chengqing 522 Aritne E flight schedule 1 1945 2 Beijing 64014 30 Chengdu 2570 6 Guangzhou 74806 7 Gu'angzhou 23768 9 Harbin 23361 111 Hohot 23361 115	14	Nanjing	3129
bangan 12074 Shenzhen 12074 18 Shenyang 6319 19 Tianjin 2300 20 Wenzhou 8636 21 Wuxi 994 22 Wuhan 16177 23 Xi'an 11988 24 Yinchuan 5346 25 Yulin 155 26 Zhangiajie 457 27 Changchun 1881 29 Zhengzhou 7282 30 Changchun 1881 29 Zhengzhou 7282 Arline E flight schedule 1945 1 Beihai 1945 2 Beijing 64014 30 Chengdu 9661 4 Dalian 2520 6 Guungzhou 74806 7 Guiyang 3834 8 Harbin 2356 12 Jinan 8647 13 </td <td>16</td> <td>Shanghai</td> <td>15303</td>	16	Shanghai	15303
3 3 6319 19 Tanjin 2300 19 Tanjin 2301 19 Tanjin 2302 21 Wuxi 904 22 Wuhan 16177 23 Xi'an 1988 24 Wuhan 155 24 Yinchuan 5346 25 Yulin 155 26 Zhangiajie 457 27 Changchun 1840 28 Changchun 1840 29 Zhengingine 64014 20 Chengghou 7928 30 Chenging 64014 21 Beijing 64014 3 Chengdu 9661 4 Dalian 2814 5 Fuzhou 2570 6 Guangzhou 11577 10 Harbin 23361 111 Hohot 2556 123 Korla 2055	17	Shenzhen	12074
19 Tanjino 2300 20 Wenzhou 8636 21 Wuxi 904 22 Wuxin 1198 24 Winan 155 25 Yulin 155 26 Zhangjajie 457 27 Changchun 1840 28 Changsha 188 29 Zhengzhou 7928 30 Chongqing 5252 Arline E flight schedule 1 145 1 Beihai 1945 2 Beijing 64014 3 Chengdu 9661 3 Chengdu 2750 6 Guangzhou 74806 7 Guangzhou 23361 11 Hohbot 2535 12 Jinan 8647 33 Guiyang 3361 11 Hohbot 2536 12 Jinan 255 13 Korla 2055 14 Kunming 19099 15	18	Shenyang	6319
20 Wenzhou 8636 21 Wuxi 904 22 Wuhan 16177 23 Xi'an 11988 24 Yinchuan 5346 25 Yulin 155 26 Zhangjajie 47 27 Changsha 1840 28 Changsha 1881 29 Zhengzhou 722 <i>Airline E Jlight schedule</i> 1945 2 Beijing 64014 2 Beijing 64014 3 Chengdu 255 6 Guangzhou 2782 7 Beijing 64014 3 Chengdu 2670 6 Guangzhou 74806 7 Guangzhou 74806 7 Guangzhou 2376 10 Harbin 2376 12 Jinan 8647 13 Korla 2055 14 Kunning 1909 15 Ihasa 1255 16 Lijiang 387 17 Miaryang 5086 18 Naning 2018 19 Naning 2018 205 </td <td>19</td> <td>Tianjin</td> <td>2300</td>	19	Tianjin	2300
21 Wuxi 904 22 Wuhan 16177 23 Xi'an 11988 24 Yinchuan 5346 25 Yulin 155 26 Zhangiajie 457 27 Changsha 1881 29 Zhengzhou 7928 Chongging 5252 Chongging 5252 Arline E flight schedule 1945 52 1 Beijing 64014 3 Chengdu 9661 4 Dalian 2814 5 Fuzhou 2570 6 Guangzhou 74806 7 Gu'yang 3834 9 Harbin 23788 9 Harbin 23781 10 Hangzhou 2356 11 Hohbot 2356 12 Jinan 8647 13 Korla 2055 16 Lijiang 3157 13 Korla 2055 14 Naning 1909 15 Lijiang 3157 16 Lijiang 3157 17 Manyang 5086 18 Nanning 2011	20	Wenzhou	8636
22 Wuhan 16177 23 Xi'an 11988 24 Yinchuan 5346 25 Yulin 155 26 Zhangjiajie 457 27 Changshan 1840 28 Changshan 1881 29 Zhengzhou 7928 Arline E flight schedule 6 6 1 Beihai 1945 2 Beijing 64014 3 Chengdu 9661 4 Dalian 2814 5 Fuzhou 2570 6 Guangzhou 74806 7 Guangzhou 74806 7 Guangzhou 2536 7 Guangzhou 23361 11 Horbiot 2536 12 Jinan 8647 13 Korla 2055 14 Horbiot 2536 15 Lhasa 1255 </td <td>21</td> <td>Wuxi</td> <td>904</td>	21	Wuxi	904
23 Xi an 11988 24 Yinchuan 5346 25 Yulin 155 26 Zhangijajie 457 27 Changchun 1840 28 Changsha 1881 29 Zhengzhou 7928 30 Chongqing 5252 Arline E flight schedule 1945 2 Beihai 1945 2 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 23361 12 Jinan 8647 13 Korla 2055 14 Kumming 19099 15 Lijang 3197 16 Lijang 3197 17 Mianyang 5086 18 Nanchang 5811 20 Nanjing 2018 21 Qingdao 17634 <t< td=""><td>22</td><td>Wuhan</td><td>16177</td></t<>	22	Wuhan	16177
24 Yuchan 5340 25 Yulin 155 26 Zhangjiajie 457 26 Changsha 1840 28 Changsha 1881 29 Zhengzhou 7928 30 Chongqing 5252 Airline E flight schedule 1 1945 1 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kumming 19099 15 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Anarjing 20118 20 Ningbo 9493 21 Qingdao 17634 23 Sanya 12234 24 Shenzhen 29324	23	Xi'an	11988
23 1100 153 26 Zhangjaje 457 27 Changchun 1840 28 Changsha 1881 29 Zhengzhou 7228 30 Chongging 5252 Arihne E flight schedule 1 1945 2 Beihai 1945 2 Beijing 64014 30 Chengdu 9661 41 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guangzhou 274806 7 Guangzhou 23708 9 Harbin 23788 9 Harbin 23361 11 Hohot 23361 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1255 16 Lijajag 3197 17 Mianyang </td <td>24</td> <td>Yinchuan</td> <td>5346</td>	24	Yinchuan	5346
20 Zhangjape 4.57 27 Changchun 1840 28 Changchun 1840 29 Zhengzhou 7928 30 Chongging 5252 Airline E flight schedule 1 1945 2 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Hatkou 11577 10 Hangzhou 23361 11 Hohhot 255 14 Jinan 8647 12 Jinan 8647 13 Korla 2055 14 Nanjing 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Nannin	25	Tulin Zhangijajja	155
23 Changshal 180 28 Changsha 181 29 Zhengzhou 7928 30 Chongqing 5252 Airline E flight schedule 1 1 1 Beihai 1945 2 Beijing 64014 3 Chengdu 961 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 2378 9 Harbou 23761 10 Hangzhou 23361 11 Hohbot 23361 12 Jinan 8647 13 Korla 2055 14 Hohbot 2356 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanting 2018 19 Nantang	20	Changebun	437
Zhengshou 7928 30 Chongqing 5252 Airline E flight schedule 1 1 1 Beihai 1945 2 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Gaugghou 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 23361 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1225 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Nanghai 62017 21 Qingdao 17634 </td <td>28</td> <td>Changsha</td> <td>1881</td>	28	Changsha	1881
30 Chongqing 5252 Airline E flight schedule 1 1945 1 Beihai 1945 2 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohbot 2536 12 Jinan 8647 13 Korla 2055 14 Hohbot 2536 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Qingdao 17634 21 Qingdao 17634 22 Qingdao 17634 23 Sanya	29	Zhengzhou	7928
Airline E flight schedule 1945 1 Beihai 1945 2 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guangzhou 74806 7 Guangzhou 2378 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kumning 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Nanjing 30662 21 Ningbo 9493 22 Qingdao 17634 23 Shanghai 62017 25 Shenzhen 29324 24	30	Chongqing	5252
1 Beihai 1945 2 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kunning 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 511 19 Naning 3666 21 Nangbao 9493 22 Qingdao 17634 23 Shanya 12234 24 Shanghai 62017 25 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8536 29 Wenzhou 8536 21 Shenyang 20311 25 Shenyang 20311	Airline E flight schedule		
2 Beijing 64014 3 Chengdu 9661 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 23361 12 Jinan 8647 13 Korla 2055 14 Korla 2055 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 581 19 Nanjing 20118 20 Nanning 3366 21 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 2924 26 Shenzhen 29314 26 Shenzhen 29314 26 <td< td=""><td>1</td><td>Beihai</td><td>1945</td></td<>	1	Beihai	1945
3 Chengdu 961 4 Dalian 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2363 12 Jinan 8647 13 Korla 2055 14 Korla 2055 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5181 19 Nanning 3366 21 Nanjing 20118 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 2924 26 Shenzhen 2924 26 Shenzhen 2934 27 Tianjin 16101 28 W	2	Beijing	64014
4 Datan 28141 5 Fuzhou 2570 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1255 16 Lijang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenzhen 29324 26 Shenzhen 29324 26 Shenzhen 29324 26 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	3	Chengdu	9661
5 Fuziou 25/0 6 Guangzhou 74806 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 20 Nanjing 20118 20 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	4	Dalian	28141
Guiyang Jaka 7 Guiyang 3834 8 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Qingdao 17634 23 Sanya 12234 24 Shenzhen 29324 25 Shenzhen 29324 26 Shenzhen 29324 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	5	Fuzilou	2370
7 10 Harbin 23788 9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kuming 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 20 Naning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	7	Guivang	3834
9 Haikou 11577 10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 20 Nanjing 20118 20 Nanjing 3366 21 Ningbo 9493 22 Qingdao 17634 23 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	8	Harbin	23788
10 Hangzhou 23361 11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Nanning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	9	Haikou	11577
11 Hohhot 2536 12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 125 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Nangbo 9493 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenzhen 29324 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	10	Hangzhou	23361
12 Jinan 8647 13 Korla 2055 14 Kunming 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 20 Nanjing 20118 20 Nanjing 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	11	Hohhot	2536
13 Korla 2055 14 Kunning 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 20 Naning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenyang 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	12	Jinan	8647
14 Kunming 19099 15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Nanning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenzhen 29324 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	13	Korla	2055
15 Lhasa 1255 16 Lijiang 3197 17 Mianyang 5086 18 Nanchang 5811 19 Nanjing 20118 20 Nanning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenzhen 29324 26 Shenzhen 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	14	Kunming	19099
10 11 <td< td=""><td>15</td><td>Lnasa</td><td>1255</td></td<>	15	Lnasa	1255
18 Nanchang 5811 19 Nanjing 20118 20 Nanning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	17	Mianyang	5086
19 Nanjing 20118 20 Nanning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	18	Nanchang	5811
20 Naning 3366 21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	19	Nanjing	20118
21 Ningbo 9493 22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	20	Nanning	3366
22 Qingdao 17634 23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	21	Ningbo	9493
23 Sanya 12234 24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	22	Qingdao	17634
24 Shanghai 62017 25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	23	Sanya	12234
25 Shenzhen 29324 26 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	24	Shanghai	62017
20 Shenyang 20311 27 Tianjin 16101 28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	25	Shenzhen	29324
28 Wenzhou 8636 29 Urumchi 4008 30 Wuxi 5038	20	Tianiin	20311
29 Urumchi 4008 30 Wuxi 5038	28	Wenzhou	8636
30 Wuxi 5038	29	Urumchi	4008
	30	Wuxi	5038

No.	City	FS
31	Wuhan	7190
32	Xi'an	31814
33	Xishuangbanna	839
34	Yinchuan	7962
35	Yulin	3421
36	Zhangjiajie	7471
37	Changchun	15336
38	Changsha	40311
39	Zhengzhou	3202
40	Chongqing	25959
Airline F flight schedule		
1	Beijing	29873
2	Chengdu	28639
3	Dalian	2774
4	Fuzhou	857
5	Guangzhou	34169
6	Harbin	9036
7	Haikou	2274
8	Hangzhou	14500
9	Hefei	3442
10	Hohhot	507
11	Kunming	4178
12	Lhasa	4573
13	Lijiang	1856
14	Mianyang	10172
15	Nanchang	12515
16	Nanjing	9388
17	Nanning	3366
18	Sanya	8156
19	Shanghai	15303
20	Shenzhen	32198
21	Shenyang	25275
22	Wenzhou	8636
23	Wuxi	2713
24	Wuhan	3210
25	Xi'an	20057
26	Yinchuan	5004
27	Yulin	155
28	Changchun	2103
29	Changsha	1881
30	Zhengzhou	8081
31	Chongqing	3001

TABLE 5. λ_i of some bases in pooling mod	TABLE	3:	λ_i	of	some	bases	in	pooling	mode
---	-------	----	-------------	----	------	-------	----	---------	------

Base <i>i</i>	Beijing	Chengdu	Dalian	Fuzhou	Guangzhou	 Zhengzhou
λ_i	2.361664	1.571812	0.729600	0.133096	1.918887	 0.285990

The red dot in Figure 9 indicates the location of the maintenance base, and the location of the red star is the optimal location of the airlines spare parts central warehouse with the lowest pooling expectation cost, whose coordinates are 113° 71′ 15.98″ E and 27° 82′ 72.61″ N. When making the plan for the location selection of the spare parts central warehouse, the lowest total cost of multiple airlines pooling should be considered but also it should be ensured that the spare parts can be quickly and efficiently transferred from the central warehouse to each base node. Therefore, on the basis of the cost optimization, locating the central warehouse

on the nearby hub airport can meet the timeliness and convenience requirements of spare parts transport. According to Figure 7, the closer the spatial distance from the cost-optimal location, the lower the pooling expectation cost, so the three hub airports with the closest spatial distance to the cost-optimal location are selected, as shown in Table 4.

When considering transport facilities and geographical environment factors, all three locations can meet the logistic requirements and transportation convenience for the supply of airlines spare parts. The sum of the annual



FIGURE 7: The pooling expectation cost with the change of central warehouse location.



FIGURE 8: PSO algorithm iteration.

operating costs for each of the six airlines operating without a pooling strategy (i.e., off-pooling strategy) for these repairable spare parts is \$267.4 million RMB. Figure 10(a) shows that the cost savings are significantly higher with the pooling strategy mentioned in the paper than that with the off-pooling strategy. Figure 10(b) shows the distance between the cost-optimal location and the three hub airport locations with iterations. It can be seen that as the location of the spare parts central warehouse tends to be closer to cost-optimal location, the adoption of the pooling strategy optimizes the total operating cost by about 136.25 million RMB compared to the off-pooling strategy in Figure 10(a). From Figure 10(b), it can be seen that the steady state is reached after 19 iterations, while the distance between the cost-optimal location and Changsha Huanghua International Airport is the shortest. Therefore, from the transport facilities and geographical environment factors perspective, the central warehouse of these repairable spare parts is selected to be located in the area near Changsha Huanghua International Airport, whose coordinates are 113° 23' 82.45" E and 28° 15' 3.16" N and will cost approximately 131.68 million RMB. Although the total cost rose by about 540,000 RMB associated with cost-optimal location, in fact, the convenience of spare parts transport can reduce the transport process and the transport risk and then improve the economic efficiency of the spare parts pooling alliance.

Clearly, the win-win effect of adopting multiple airlines to implement the airlines spare parts pooling strategy is significant. Finally, Figure 11 demonstrates comparison of the operational status of each indicator between the pooling and off-pooling strategies for airlines spare parts while ensuring other conditions are consistent.

It can be seen that, with the guarantee of 98% filling rate, the total inventory of spare parts required by all maintenance bases is significantly less than the off-pooling strategy when the pooling strategy is adopted, which relatively reduces the size of spare parts by 64.46% and optimizes the operation cost by 50.76%. However, the daily AOG time is higher in the pooling strategy than that in off-pooling strategy. It is because under the off-pooling strategy, the maintenance bases are supplied directly from each airline's headquarters inventory, which is generally located in the more central location of all flight routes with



FIGURE 9: The optimal location for the airlines spare parts central warehouse.

TABLE 4: Three hub airports information with the closest spatial distance to the cost-optimal location.

Airports	Coordinates	Cost
Changsha Huanghua International Airport	(113°23′82.45″ E, 28°15′3.16″ N)	131.68 million RMB
Nanchang Changbei International Airport	(115°90′29.42″ E, 28°84′68.78″ N)	143.51 million RMB
Wuhan Tianhe International Airport	(114°25′93.49″ E, 30°81′76.41″ N)	144.98 million RMB



FIGURE 10: The cost savings advantages of pooling strategy and the variation of the distance between the cost-optimal location and three hub airport locations. (a) The cost savings by adopting pooling strategy compared to the off-pooling strategy. (b) The variation of distance between the cost-optimal location and the three hub airport locations with iterations.



FIGURE 11: Comparison of the operation status of each indicator between the pooling and off-pooling strategies for airlines spare parts.

a shorter average direct transfer cycle. Moreover, each airline will stock large amount of inventory at each maintenance base in order to ensure the 98% fill rate. However, this approach will cause redundancy of spare parts and generate unnecessary costs. If the scale of airlines spare parts arranged in the off-pooling strategy is deployed by using the pooling strategy, it can ensure a higher fill rate of spare parts in the global environment and develop a greater scale effect. Therefore, it is meaningful to adopt pooling strategy for the overall layout of airlines spare parts.

6. Conclusions

This paper proposes a multiairline spare parts pooling supply strategy based on METRIC theory and establishes a central warehouse location selection model for the spare parts pooling network based on $M/M/s/\infty/\infty$ multiservice desk model and considers three cost factors including spare parts transfer cost, AOG loss cost, and spare parts storage cost. Subsequently, the PSO algorithm is combined with the example for model validation and simulation analysis, and the result of location selected is adjusted according to the transportation facilities and geographical environment factors around the location site. Finally, the paper compares the results of airlines operating under pooling and off-pooling strategies to verify the validity of the strategy and model. The method developed in this paper will be able to provide a theoretical basis for making effective decisions on airlines pooling and the location selection of airlines spare parts central warehouse.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported by the Civil Aviation Science and Technology Project, the Scientific Research Foundation for the Returned Overseas Chinese Scholars, State Education Ministry, Tianjin Natural Science Foundation, 18JCYBJC42300, and Scientific Research Project of Tianjin Education Commission, 2019KJ143. The authors would like to extend their sincere gratitude to Prof. You-min Zhang from Concordia University, Canada, for his instructive advices and suggestions on this paper.

References

- J. Wang, X. Pan, L. Wang, and W. Wei, "Method of spare parts prediction models evaluation based on grey comprehensive correlation degree and association rules mining: A case study in aviation," *Mathematical Problems in Engineering*, vol. 2018, Article ID 2643405, 10 pages, 2018.
- [2] Y. Feng, J. Chen, J. Liu, C. Lu, and X. Xue, "Review on the civil aircraft spare parts prediction and configuration management technology," *Advances in Aeronautical Science and Engineering*, vol. 11, no. 4, pp. 443–453, 2020.
- [3] J. Xu, H. Zuo, and L. Sun, "A two-echelon two-indenture inventory model for repairable spare parts based on VMI," *Aircraft Design*, vol. 35, no. 3, pp. 55–60, 2015.
- [4] S. Van der Auweraer, R. N. Boute, and A. A. Syntetos, "Forecasting spare part demand with installed base information: A review," *International Journal of Forecasting*, vol. 35, no. 1, pp. 181–196, 2018.
- [5] Z. Cai, J. Jin, and Y. Chen, "Optimal inventory modeling of spare parts under the criticality," *Systems Engineering and Electronics*, vol. 39, no. 8, pp. 1765–1773, 2017.
- [6] L. Zhou, Q. Li, Y. Peng, and H. Li, "Optimization model for multi-level and multi-echelon spare part allocation in dynamic support structure," *Acta Aeronautica et Astronautica Sinica*, vol. 38, no. 11, pp. 155–167, 2017.
- [7] Q. Mathias, M. André, and O. Boris, "Optimisation model for multi-item multi-echelon supply chains with nested multilevel products," *European Journal of Operational Research*, vol. 290, no. 1, pp. 144–158, 2021.

- [8] C. Ruiz, H. Luo, H. Liao, and W. Xie, "Component replacement and reordering policies for spare parts experiencing two-phase on-shelf deterioration," *IISE Transactions*, vol. 52, no. 1, pp. 75–90, 2020.
- [9] Y. Feng, K. Liu, X. Xue, and Y. Liu, "Joint optimization of redundancy level and spare parts for redundant system based on Markov process," *Systems Engineering and Electronics*, vol. 41, no. 4, pp. 921–930, 2019.
- [10] C. C. Sherbrooke, "Metric: A multi-echelon technique for recoverable item control," *Operations Research*, vol. 16, no. 1, pp. 122–141, 1968.
- [11] Y. Chen, L. Liu, V. Shi, Y. Zhang, and J. Zhu, "The optimization of a virtual dual production-inventory system under dynamic supply disruption risk," *Complexity*, vol. 2020, Article ID 7067502, 12 pages, 2020.
- [12] M. Ruan, R. Wang, and Q. Kong, "Mission-oriented configuration model of aircraft carrying spares and dynamic optimization policy," *Transactions of Nan Jing University of Aeronautics & Astronautics*, vol. 33, no. 5, pp. 626–632, 2016.
- [13] J. F. Burns and B. D. Sivazlian, "Dynamic analysis of multiechelon supply systems," *Computers & Industrial Engineering*, vol. 2, no. 4, pp. 181–193, 1978.
- [14] P. Wang and T. Jin, "Parametric uncertainty analysis of complex system reliability," *International Journal of Performability Engineering*, vol. 5, no. 2, pp. 197–199, 2009.
- [15] J. A. Muckstadt, "A model for a multi-item, multi-echelon, multi-indenture inventory system," *Management Science*, vol. 20, no. 4, pp. 472–481, 1973.
- [16] S. C. Graves, "A multi-Echelon inventory model for a repairable item with one-for-one replenishment," *Management Science*, vol. 31, no. 10, pp. 1247–1256, 1985.
- [17] W. Y. Yun, W. Jeon, and Q. Q. Zhao, "Spare parts provisioning under multi-Echelon and multi-level systems," *Journal of Applied Reliability*, vol. 18, no. 4, pp. 370–379, 2018.
- [18] S. Zhang, K. Teng, F. Xiao, and Y. Sun, "Multi-echelon and Multi-indenture inventory optimal model for carrier-based aircraft repairable spare parts based on vari-metric model," *Fire Control and Command Control*, vol. 40, no. 9, pp. 157– 162, 2015.
- [19] Y. Feng, Y. Li, X. Xue, and C. Lu, "Multi-echelon inventory allocation under imperfect repair for repairable spares of civil aircraft," *Journal of Northwestern Polytechnical University*, vol. 35, no. 5, pp. 827–833, 2017.
- [20] R. He, H. Li, B. Zhang, and M. Chen, "The multi-level warehouse layout problem with uncertain information: uncertainty theory method," *International Journal of General Systems*, vol. 49, no. 5, pp. 497–520, 2020.
- [21] Y. Ai, D. Cao, B. Shen, and J. Lv, "Bi-level optimization model of VTS center layout and radar station location-configuration," *Journal of Dalian Maritime University*, vol. 43, no. 3, pp. 107–111, 2017.
- [22] A. S. Claudio, A. M. Pablo, and P. B. Germán, "Lagrangian relaxation for an inventory location problem with periodic inventory control and stochastic capacity constraints," *Mathematical Problems in Engineering*, vol. 2018, Article ID 8237925, 27 pages, 2018.
- [23] Z. Li and J. Hai, "A capacitated location-inventory model with demand selection," *Journal of Advanced Transportation*, vol. 2019, Article ID 2143042, 11 pages, 2019.
- [24] E. Setiawan, "Location-allocation models for relief distribution and victim evacuation after a sudden-onset natural disaster," Ph. D. thesis, Loughborough University, England, UK, 2015.

- [25] J. Cai, Y. Yin, L. Zhang, and X. Chen, "Joint optimization of preventive maintenance and spare parts inventory with appointment policy," *Mathematical Problems in Engineering*, vol. 2017, Article ID 3493687, 12 pages, 2017.
- [26] I. S. Doolun, S. G. Ponnambalam, N. Subramanian, and G. Kanagaraj, "Data driven hybrid evolutionary analytical approach for multi objective location allocation decisions: Automotive green supply chain empirical evidence," *Computers and Operations Research*, vol. 98, pp. 265–283, 2018.
- [27] X. Mu, J. Guo, Z. Yang, and D. Cheng, "Study on the site selection of emergency material reserve point based on multiobjective decision method," *Journal of Computational Methods in Science and Engineering*, vol. 16, no. 3, pp. 481– 492, 2016.
- [28] H. Said and K. El-Rayes, "Optimizing material procurement and storage on construction sites," *Journal of Construction Engineering and Management*, vol. 137, no. 6, pp. 421–431, 2011.
- [29] Y. Wang, X. Ma, Y. Wang, H. Mao, and Y. Zhang, "Location optimization of multiple distribution centers under fuzzy environment," *Journal of Zhejiang University-Science A*, vol. 13, no. 10, pp. 782–798, 2012.
- [30] S. Li, Z. Wei, and A. Huang, "Location selection of urban distribution center with a mathematical modeling approach based on the total cost," *IEEE Access*, vol. 6, pp. 61833–61842, 2018.
- [31] W. Li, X. Dong, Q. Zhu, and Z. He, "Multi-objective location model of spare parts support center based on reliability," *Journal of Nanjing University of Aeronautics and Astronautics*, vol. 51, no. 6, pp. 835–840, 2019.
- [32] P. Batchoun, J. A. Ferland, and R. Cléroux, "Allotment of aircraft spare parts using genetic alorithms," *Pesquisa Operacional*, vol. 23, no. 1, pp. 141–159, 2003.
- [33] Y. Li and W. Fan, "Optimization model of aviation spares inventory control based on genetic algorithm," *Computer Technology and Development*, vol. 24, no. 11, pp. 186–189, 2014.
- [34] J. Tian, E. Zhang, and W. Fu, "Application of improved quantum particle swarm algorithm in initial configuration of aircraft spare parts," *Journal of Civel Aviation University of China*, vol. 36, no. 5, pp. 48–51, 2018.
- [35] J. Zhang and H. Li, "Application of multi-objective ant lion optimizer in optimization of aviation parts allocation," *Computer Simulation*, vol. 36, no. 7, pp. 71–74+115, 2019.
- [36] N. A. Mohd-Lair, C. K. Pang, W. Y. H. Liew, H. Semui, and L. Z. Yew, "An EOQ based multi-storage location of spare part inventories: A case study," *Applied Mechanics and Materials*, vol. 315, pp. 733–738, 2013.
- [37] L. Liu, Z. Huang, and S. Liu, "Research into generalized maintenance process for air force station repairable equipment," *Operations Research and Management Science*, vol. 28, no. 10, pp. 1–4, 2019.
- [38] L. Sun and H. Zuo, "Optimal allocation modeling for initial spare parts of civil aircraft based on METRIC," *China Mechanical Engineering*, vol. 24, no. 23, pp. 3200–3204, 2013.
- [39] VariFlight Ltd., VariFlight Big Date, VariFlight Ltd., Hefei, China, 2021, https://data.variflight.com/.
- [40] Civil Aviation Administration of China, Statistical Data on Civil Aviation of China 2019, China Civil Aviation Publishing House, Beijing, China, 2019.