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Research Article

Dispatching Plan Based on Route Optimization Model Considering Random Wind for Aviation Emergency Rescue

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Aviation emergency rescue is an effective means of nature disaster relief that is widely used in many countries. The dispatching plan of aviation emergency rescue guarantees the efficient implementation of this relief measure. The conventional dispatching plan that does not consider random wind factors leads to a nonprecise quick-responsive scheme and serious safety issues. In this study, an aviation emergency rescue framework that considers the influence of random wind at flight trajectory is proposed. In this framework, the predicted wind information for a disaster area is updated by using unscented Kalman filtering technology. Then, considering the practical scheduling problem of aircraft emergency rescue at present, a multiobjective model is established in this study. An optimization model aimed at maximizing the relief supply satisfaction, rescue priority satisfaction, and minimizing total rescue flight distance is formulated. Finally, the transport times of aircraft with and without the influence of random wind are analyzed on the basis of the data of an earthquake disaster area. Results show that the proposed dispatching plan that considers the constraints of updated wind speed and direction is highly applicable in real operations.

1. Introduction

Among all countermeasures for disaster relief and emergency response treatment, air rescue is the most effective and popular one globally; this approach offers the advantages of high speed, high efficiency, and few geospatial constraints [1, 2]. Air rescue requires quick reaction, efficient performance, scientific implementation, and safe operation. This scientific implementation shows that air rescue is a technologically demanding collaborative operation whose goals can only be achieved through scientific organization. In recent years, earthquake rescue [3–11] is disorganized in terms of goods distribution and limited in terms of the uniform configuration of air transport capacity. Thus, immediate and in-depth research is required to improve the integrated scheduling of air rescue goods and transport capacity.

Literature Overview. A number of researchers have conducted intensive investigations on resource scheduling in emergency rescue. Emergency resource scheduling includes static and dynamic scheduling. Static scheduling involves the selection of proper emergency rescue points among multiple optional rescue points and the definition of the staff quantity of each rescue point to meet emergency resource requirements. Holguín-Veras et al. [12] developed a multiobjective selection model to select rescue points that can be reached in the shortest time after an emergency. Holguín-Veras et al. [12] also discussed a method and algorithm for the multiobjective and multirescue point selection of the minimum number of emergency rescue points that can be reached in the shortest time. Rennemo et al. [13] examined the decision support system of relief logistics and the multistage and multiobjective distribution of relief goods. Toro-Díaz et al. [14] developed a mathematical formulation that combines an integer programming model representing location and dispatching decisions with a hypercube model representing queuing elements and congestion phenomena. Dispatching decisions are modeled as a fixed priority list for each customer. Apart from the aforementioned conclusive issues, static scheduling also includes some inconclusive issues, such as the optimization of a combination of rescue points of a certain single disaster area [8] and research on large-scale emergency with multiple coexisting disaster areas [8, 9, 15, 16].

Static emergency resource scheduling is the primary issue of optimizing a combination of rescue points. However, in practice, resource scheduling is often conducted in multiple stages because of inadequate information. The resource amount scheduled at a certain stage is closely linked to the resource amount scheduled at the prior stage. Therefore, the dynamic resource scheduling model [17–19] is practically important. To meet the aforementioned requirements, Abounacer et al. [17] considered a three-objective location-transportation problem for disaster response and proposed an epsilon-constraint method for this problem; this method was proven to be capable of generating an exact Pareto front. Sheu [18] focused on resource demand forecasting and analyzed the critical influencing factors of resource scheduling to achieve dynamic resource scheduling. Rawls and Turnquist [19] constructed a dynamic allocation model to optimize prevention planning for meeting short-term demands (over approximately the first 72 h) for emergency supplies under uncertainty about which demands need to be met and where such demands will occur. Dynamic resource scheduling should be based on the accurate gathering of resource information. The scheduling plan should be optimized in accordance with the prior stage of the emergency relief effect and the current status. Decision making on scheduling is time-critical and dynamic. Considering the dynamic change of resource information in the rescuing process, the follow-up decision can be affected by the reckoning error of the prior stage. This effect is especially evident if the dynamic scheduling discipline is determined using only the probability calculation of emergency prearranged planning. This situation can directly influence the rationality of dynamic resource scheduling.

Meanwhile, the demand difference of various types of emergency goods and the fuel consumption of aircraft can lead to divergent scheduling decisions. Moreover, the conventional dispatching plan [9] pays close attention to demand material distribution; hence, multiple real factors affecting the quick response of emergency rescue are subordinated. Random wind at the range of flight trajectory is the primary factor that causes the deviation between preplanned flight trajectory and practical flight trajectory in the process of aviation emergency rescue. Furthermore, random wind can permute the result of total airplane dispatching plan and can threaten the security of aviation emergency rescue. Thus, to achieve a more efficient and safer airplane dispatching plan, random wind factor must be considered in aviation emergency rescue models. In this study, an aviation emergency rescue framework that considers the influence of random wind at flight trajectory is proposed.

Proposed Approach. The dispatching plan of aviation emergency rescue guarantees the efficient implementation of this relief measure. The conventional dispatching plan that does not consider random wind factors leads to a nonprecise quick-responsive scheme and serious safety issues. Therefore, an aviation emergency rescue framework that considers the influence of random wind at flight trajectory is proposed. The contributions of this paper are as follows: (1) we propose an aviation emergency rescue framework that considers the influence of random wind at flight trajectory; (2) rescue priority satisfaction, as an object function, is added in the optimization model which can acquire rescue plan of heavy disaster area; (3) the proposed model is compared with the emergency logistics distribution model in [9], and the results confirm that the proposed model is more feasible and applicable to practical situations.

The rest of the paper is organized as follows. In Section 2, the updated predicted wind information at flight trajectory was acquired with the unscented Kalman filtering (UKF) fusion technology. Then, an airplane motion model with the influence of random wind was built. In Section 3, an aviation emergency rescue dispatching plan model with the constraints of rescue priority and random wind was proposed and solved using Lingo. In Section 4, a case study was implemented to verify the feasibility and effectiveness of the model. Finally, in Section 5, conclusions were drawn.

2. Airplane Motion Model under the Influence of Random Wind

2.1. Prediction of Random Wind Based on UKF. UKF is an algorithm that combines unscented transformation and Kalman filtering [20], and strong stochastic turbulence is the most important characteristic of random wind. UKF can deal with stochastic turbulence. Hence, UKF technology was applied to update the predicted random wind information in this study. To obtain accurate random wind information, we used the data from an international ground exchange station in the rescue airspace. The grid predicted data of random wind, which were stored at NetCDF format, were obtained from the World Aero Forecast System. The predicted data were obtained by combining the weather data based on UKF technology [21]. Each airport is equipped with one or more international ground exchange stations. Thus, the updated predicted wind information at the flight trajectory between any two rescue points can be drawn through a linear interpolation model.

Assuming that x is the state vector of L with a mean of $\overline{x}$ and a variance of P_x and according to the statistics $\overline{x}$ and P_x of x, $2L+1$ weighted sample points $S_i = \{W_i, \chi_i\}$, $i = 1, \ldots, 2L+1$ are selected to approximate the distribution of the state vector x, in which W_i is the weight of χ_i and χ_i and is called the σ point. The σ set is obtained as follows:

$$\chi_i = \begin{cases} \overline{x}, & i = 0 \\ \overline{x} + \left(\sqrt{(L+\lambda)\,P_x}\right)_i, & i = 1, \ldots, L \\ \overline{x} - \left(\sqrt{(L+\lambda)\,P_x}\right)_{i-L}, & i = L+1, \ldots, 2L, \end{cases} \quad (1)$$

where λ is the scale parameter. Adjusting λ can improve approximation accuracy. This group of sample points χ_i can approximately represent the Gaussian distribution of the state vector x.

After the $f(\cdot)$ nonlinear transformation of the constructed point set $\{\chi_i\}$, the transformed σ set $Y_i = f(\chi_i)$,

$i = 0, 1, \ldots, 2L$, can be obtained. The transformed σ set $\{Y_i\}$ can approximately represent the distribution of $y = f(x)$.

$$\overline{y} \approx \sum_{i=0}^{2L} W_i^{(m)} Y_i,$$
$$P_y \approx \sum_{i=0}^{2L} W_i^{(c)} (Y_i - \overline{y})(Y_i - \overline{y})^T, \quad (2)$$

where $W_i^{(m)}$ and $W_i^{(c)}$ are the weights for calculating the mean and variance of y, respectively. The calculation formula is given by

$$W_0^{(m)} = \frac{\lambda}{L+\lambda},$$
$$W_0^{(c)} = \frac{\lambda}{L+\lambda} + (1 - \alpha^2 + \beta), \quad (3)$$
$$W_i^{(m)} = W_i^{(c)} = \frac{1}{2(L+\lambda)}, \quad i = 1, \ldots, 2L,$$

where $\lambda = \alpha^2(L+\kappa) - L$.

Three parameters, namely, α, β, and κ, must be determined in the mean and variance weighting. Their significance and value ranges are as follows. The value of α determines the distribution of σ around $\overline{x}$, which is usually set to a small positive number ($1e^{-3} \leq \alpha < 1$); here, $\alpha = 0.001$. β is the state distribution parameter, with $\beta = 2$ being the optimal value for a Gaussian distribution. If the state variable is a single one, $\beta = 0$ is the optimal value. κ is the second scale parameter, which is usually set to 0 or $3 - n$, n is the dimension of state variable. The proper adjustment of α and κ can improve the accuracy of the estimated mean; such adjustment can improve the precision of variance.

The values of wind speed and direction with respect to the time series can be regarded as the discrete nonlinear system as follows:

$$x_{k+1} = f(x_k) + w_k,$$
$$y_k = h(x_k) + v_k. \quad (4)$$

Assuming that the process noise w_k and the measurement noise v_k are the white Gaussian noises with a mean of 0 and covariances of Q_k and R_k, respectively, and are unrelated to each other, the UKF algorithm is represented as follows:

(1) Initialization condition is as follows:

$$\widehat{x}_0 = E[x_0],$$
$$P_0 = E\left[(x_0 - \widehat{x}_0)(x_0 - \widehat{x}_0)^T\right]. \quad (5)$$

(2) For $k \in \{1, \ldots, \infty\}$, σ is calculated to obtain

$$\chi_{k-1}^a = \left[\widehat{x}_{k-1}^a \widehat{x}_{k-1}^a \pm \sqrt{(L+\lambda) P_{k-1}^a}\right]. \quad (6)$$

(3) Time propagation equation is as follows:

$$\chi_{k|k-1}^x = F\left[\chi_{k-1}^x, \chi_{k-1}^v\right],$$
$$\widehat{x}_k^- = \sum_{i=0}^{2L} W_i^{(m)} \chi_{i,k|k-1}^x,$$
$$P_k^- = \sum_{i=0}^{2L} W_i^{(c)} \left[\chi_{i,k|k-1}^x - \widehat{x}_k^-\right]\left[\chi_{i,k|k-1}^x - \widehat{x}_k^-\right]^T, \quad (7)$$
$$Y_{k|k-1} = H\left[\chi_{k|k-1}^x, \chi_{k-1}^n\right],$$
$$\widehat{y}_k^- = \sum_{i=0}^{2L} W_i^{(m)} Y_{i,k|k-1}.$$

(4) Measurement updating equation is as follows:

$$P_{\overline{y}_k \overline{y}_k} = \sum_{i=0}^{2L} W_i^{(c)} \left[Y_{i,k|k-1} - \widehat{y}_k^-\right]\left[Y_{i,k|k-1} - \widehat{y}_k^-\right]^T,$$
$$P_{x_k y_k} = \sum_{i=0}^{2L} W_i^{(c)} \left[\chi_{i,k|k-1} - \widehat{x}_k^-\right]\left[Y_{i,k|k-1} - \widehat{y}_k^-\right]^T,$$
$$K = P_{x_k y_k} P_{\overline{x}_k \overline{y}_k}^{-1}, \quad (8)$$
$$\widehat{x}_k = \widehat{x}_k^- + K(y_k - \widehat{y}_k^-),$$
$$P_k = P_k^- - K P_{\overline{y}_k \overline{y}_k} K^T.$$

In (5) to (8), the subscript k in the variables refers to the discrete time point in the data sequence of wind speed or direction, and the serial number i refers to the ith component of the vector. $\widehat{x}_k$ is the estimate of the system state at k by the UKF algorithm, and P_k is the estimate of the system state variance at k. The predicted values obtained with the UKF algorithm are different from the NWP data. Such difference is known as the system error of numerical prediction. After correcting the error according to the original predicted values, highly accurate wind speed and direction values can be obtained.

2.2. Airplane Motion Model under the Influence of Random Wind. In this subsection, an airplane motion model was built. The synthesis of random wind speed and true airplane airspeed is described in Figure 1.

By analyzing the historical random wind data from the international ground exchange station, we assumed that the wind speed components u and v obey the normal distribution [22]. The blue normal curve was used to represent the random wind vector, in which the average speeds were u_{wind} and v_{wind} in the u and v directions, denoted as $u_{\text{wind}} \sim N(\mu_1, \sigma_1)$ and $v_{\text{wind}} \sim N(\mu_2, \sigma_2)$, respectively. Then, the true airspeed was divided into the two directions. The airplane ground speed, which is the sum velocity of random wind speed and true airplane airspeed, was obtained with the vector synthesis principle. Therefore, the red normal curve was defined to describe the airplane ground speed, with the average speeds being u_{GS} and v_{GS} in the u and v directions, respectively. The internal relationships among these parameters were satisfied as $u_{\text{GS}} = u_{\text{wind}} + v_{\text{TAS}} \sin\alpha$ and $v_{\text{GS}} = v_{\text{wind}} + v_{\text{TAS}} \cos\alpha$.

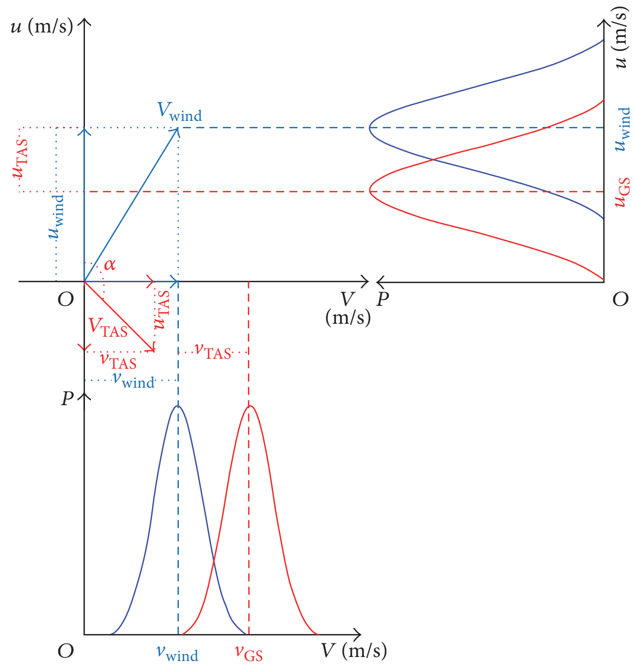

Figure 1: Normal composite of random wind speed and true airplane speed.

3. Scheduling Optimization Model

The scheduling problem in this study refers to the reasonable arrangement of flight routes of aircraft in a supply-demand relation system. This system involves several aircraft, rescue points, and devastated points. The main aim is to achieve the optimal values of different objective functions while meeting the constraints (e.g., maximum payload constraint of the aircraft, maximum flight radius constraint of the aircraft, and material demand constraint). The objective functions are as follows: (1) maximum supply satisfaction at devastated point: protecting the safety of rescue workers is the primary goal of disaster relief. A high supply satisfaction can mobilize all rescue forces fully in unit time and achieve the maximum rescue efficiency; (2) shortest total mileage of transport: mileage of transport is directly related to the maximum fuel load, average fuel consumption per hour, average flight speed of the aircraft, and degree of fatigue of the aircrew. A reasonable mileage of transport can shorten rescue time to ensure prompt rescue, reduce rescue cost, and increase the economic efficiency of rescue scheduling. Moreover, such function can eliminate the fatigue of the aircrew and increase flight security; (3) highest rescue priority satisfaction: some devastated points are strict with regard to the rescuing urgency. To improve scheduling task quality, rescue priority satisfaction should also be considered as one of the goals of aircraft scheduling solution.

3.1. Concepts and Definitions Involved in Aircraft Scheduling

3.1.1. Relief Supplies. Supplies are the object of transportation. Relief supplies of every devastated point or rescue point can be viewed as a consignment of goods. Such goods feature different types of attributes (e.g., fast-moving consumer goods or durable goods), weight and volume, required arrival time and devastated point, and permission of partial distribution. Weight of supplies is the basis of decision making on aircraft load. If the demand for supplies of one devastated point exceeds the maximum payload of the aircraft, then rearranging another aircraft is necessary. The rescue priority of devastated points and the distance between rescue points are the basis of flight route planning for aircraft.

3.1.2. Aircraft. It is the carrier of relief supplies, and its main attributes include type, maximum fuel load, fuel consumption per hour, average flight speed, maximum climb rate, ceiling, and maximum payload. Aircraft participating in rescue mainly includes different models of helicopters of General Aviation and some large-load transport planes. In this study, M-171, M-8, Y7-100, and Y5-B(K) are chosen as the rescuing aircrafts. The maximum payload of aircraft refers to the maximum loading weight of the aircraft. It is the primary constraint of aircraft performance and an important reference for scheduling decision making. Aircraft must return to the starting point after the delivery of supplies.

3.1.3. Rescue Point. It is the place supplied with the relief goods and the command central hub of aircraft. A distribution scheduling task can involve one or several central hubs, and the offered relief supplies can be a single variety or diversified. The total material storage can meet all or the partial demands for supplies of all devastated points.

3.1.4. Devastated Point. Its attributes include material demands, rescue priority, and material satisfaction. In a distribution system, the material demands of one devastated point can be larger or smaller than the maximum payload of one aircraft. Rescue priority is divided according to the actual disaster conditions of devastated points and is integral within a certain range. Relief supply satisfaction includes full satisfaction and partial satisfaction.

3.1.5. Transport Network. It is composed of vertexes (rescue points and devastated points) and directed arc. The attributes of sides and arcs include direction, weight, material distribution quantity, and traffic flow limit. Weight can be expressed in time, cost, or distance. This attribute can also either change with time or type of aircraft or remain constant. The traffic flow of vertexes, sides, and arcs in the transport network can be considered as infinite flow, such as the quantity of aircraft loading or unloading in the same rescue point and flying in the same sides and arcs.

3.2. Model Hypotheses

(1) Aircrafts influenced by random winds deviate from the planned route. To ensure that the aircraft follows the planned route, the track angle should be equivalent to the course angle and thus offset the bias caused by crosswind.

(2) When several rescue points are available for different groups of devastated points, locations of rescue points and devastated points are fixed. In addition, different

types of relief supplies in the rescue points can meet the material demands of devastated points.

(3) The mixing of material loadings of different devastated points is allowed. In other words, relief supplies for different devastated points can be loaded onto the same aircraft.

(4) The relief supplies of every devastated point should be satisfied at the lowest extent and be distributed by one aircraft. No partial shipment is allowed.

(5) The material loads of every aircraft should not exceed its maximum payload.

(6) Given that the maximum fuel load of aircraft is fixed, the maximum flight distance of every aircraft should not exceed its maximum flight radius.

(7) During material distribution, every aircraft should take off from the rescue point and return to the rescue point after delivering relief supplies to the devastated points in the area under administration.

(8) The time interval in this study is extremely short. Therefore, relief supplies of rescue points and the material demands of devastated points are kept the same in the defined period.

(9) Aircraft can only be refueled and loaded in rescue points, and they can only release or unload supplies at devastated points.

3.3. Objective Functions and Constraints. In this subsection, the model variables are provided in Notations.

For every devastated point group, the objective functions of maximum relief supply satisfaction $F_g^1(t)$, maximum rescue priority satisfaction $F_g^2(t)$, and the shortest total mileage of aircraft $F_g^3(t)$ in the given time interval t are

$$\begin{aligned}
\max \quad & F_g^1(t) = \frac{\sum_{\forall l}\sum_{m=1}^{M}\sum_{\forall ig\in g} X_{m,ig}^l(t)}{\sum_{\forall l}\sum_{\forall ig\in g} D_{ig}^l(t)}, \quad \forall (g,t), \\
\max \quad & F_g^2(t) = \sum_{i=1}^{n_{mk}} W_{ig}\left(n_{mk}+1-r_{mji}\right), \\
\min \quad & F_g^3(t) \\
& = \sum_{m=1}^{M}\sum_{k=1}^{K}\sum_{i=1}^{n_{mk}}\left\{\left(d_{r_{mj(i-1)}r_{mji}} + d_{r_{mjn_{mk}}r_{mj0}}\right)\cdot \operatorname{sign}\left(n_{mk}\right)\right\}.
\end{aligned} \tag{9}$$

The constraints are

$$\mathrm{LD}_{ig}^l(t) \le \sum_{m=1}^{M} X_{m,ig}^l(t) \le D_{ig}^l(t), \quad \forall g, ig, l, t, \tag{10}$$

$$\sum_{\forall ig\in G_g}\sum_{m=1}^{M} X_{m,ig}^l(t) \le \sum_{m=1}^{M} S_{m,G_g}^l(t), \quad \forall g, G_g, l, t, \tag{11}$$

$$\sum_{\forall l}\sum_{\forall ig\in G_g} X_{m,ig}^l \le Q_{mk}, \quad \forall m, ig, k, \tag{12}$$

$$\sum_{i=1}^{n_{mk}} d_{r_{mj(i-1)}r_{mji}} + d_{r_{mjn_{mk}}r_{mj0}} \le \left(\frac{f_{mk}}{c_{mk}}\right)\cdot v_{mk}, \quad \forall m, k, j, \tag{13}$$

$$\sum_{k=1}^{K} n_{mk} = L_m, \quad \forall m, \tag{14}$$

$$\sum_{m=1}^{M} L_m = N, \tag{15}$$

$$0 \le n_{mk} \le L_m, \tag{16}$$

$$\operatorname{sign}\left(n_{mk}\right) = \begin{cases} 1, & n_{mk} \ge 1 \\ 0, & \text{else}, \end{cases} \tag{17}$$

$$X_{m,ig}^l(t) \ge 0, \quad \forall g, ig, l, m, t, \tag{18}$$

$$W_{ig} \in (1,5), \tag{19}$$

$$\bar{v}_{mk} = \frac{1}{H_j}\sum_{h=1}^{H_j} v_{mkj}^h, \quad \forall m, k, j. \tag{20}$$

Constraint (10) ensures that the total relief supplies to any devastated point are larger than the minimum demands and smaller than the actual demands in any time interval. Constraint (11) ensures that the total relief supplies to all devastated points of any group g in any time interval are controlled lower than the supply of the corresponding rescue point. Constraint (12) protects every aircraft from overloading. Constraint (13) ensures that the flight distance of every aircraft is within the maximum flight radius. Constraint (14) ensures that all devastated points in the administration area of every rescue point receive relief supplies. Constraint (15) ensures that all devastated points receive relief supplies. Constraint (16) ensures that the serviced devastated points of the kth aircraft from rescue point m are controlled to be smaller than the number of devastated points in the administration of rescue point m. Constraint (17) indicates that when $n_{mk} \ge 1$, $\operatorname{sign}(n_{mk}) = 1$, this aircraft participated in the rescue; otherwise, it did not. Constraint (18) ensures the nonnegativity of relief supplies to any devastated point at any time, resulting in the practical significance of the problem. Constraint (19) means that the preset rescue priority is any integral between 1 and 5. Constraint (20) reflects the average flight speed of the kth aircraft at rescue point m. It is convenient to assume the actual flight speed of the aircraft v_{mk} obey the normal distribution during the whole time period (e.g., per half hour) and each small piece of time (5 minutes), which can be seen as the average speed of solution.

3.4. Model Solving. In this study, the proposed model and the emergency logistics distribution model in [9] were solved using the Lingo software. Their calculated results were analyzed and compared. The solution of the model mainly includes grouping of devastated points, route planning in the group, and allocation of relief supplies, and detailed steps are as follows.

Step 1. Get the preliminary information of the disaster area, and determine the relief supplies of rescue points, disaster relief priorities, and supplies demand of devastated points.

Step 2. According to the distance d_{ij} between the rescue points and the devastated points, divide the rescue points into the nearest group, namely g group.

Step 3. Take one of the group, and make an initial planning for the aircrafts and materials within the group to meet the objectives which include the shortest total mileage of aircrafts, maximum rescue priority satisfaction, and maximum relief supply satisfaction.

Step 4. Obtain aircraft flight performance, and estimate whether the actual flight mileage of all aircraft $\sum d_{ij}$ within the group is less than its flight radius. We continue the next step if it is true; if not, we jump to the Step 3 and replanning.

Step 5. Adopting aircraft flight performance, estimate whether the total distribution amount of all rescue aircraft $\sum X_{ij}$ is less than its maximum load. We continue the next step if it is true; if not, we jump to the Step 3 and replanning.

Step 6. According to the amount of material supply and demand in Step 1, estimate whether the actual distribution amount of the rescue aircraft X_{ij} is greater than the lowest demand amount of devastated point LD_g and less than the relief supplies of rescue points $\sum S_g$. We continue the next step if it is true; if not, we jump to the Step 3 and replanning.

Step 7. Through the above steps, we can complete the allocation of resources and path planning in any group. Then we repeat the operation of Steps 3–6 for other groups to complete the whole dispatching plan of the emergency rescue.

Following the above seven steps and combining with the rescue scene, we can get an optimal solution, which meets three objective functions and all constraints. However, we could not meet all the model optimal solution in many practical rescue. Therefore, we should take the suboptimal solution of the model into consideration. First of all, one or more feasible path of the rescue can be gotten when we meet the maximum target priority satisfaction. Secondly, when we meet the greatest satisfaction of material distribution and do not meet the maximum relief supply satisfaction, we can find the shortest path of total flight mileage in the rescue. So we could take second shortest path, or we find the result which meet shortest total mileage and do not meet maximum relief supply satisfaction. These possible solutions are called suboptimal solutions. In short, we can find the solution of three objective functions successively to get the relative optimal solution in the second-best solution.

4. Simulation and Experiment

4.1. Parameter Settings. The feasibility and validity of the proposed model were verified with the seismic data based on Wenchuan earthquake in Sichuan Province of China. The supply of rescue points and demands as well as the rescue priority of devastated points were determined according to actual disaster conditions in different regions. The parameters are listed in Tables 1 and 2. A total of 3 rescue points and 18 devastated points were involved.

Table 1: Supply of rescue points.

Number	Name	Supply/(kg) S_i^0	Supply/(kg) S_i^1
1	Chengdu Shuangliu Airport	6000	4000
2	Yibin Airport	6000	4000
3	Guangyuan Panlong Airport	6000	4000

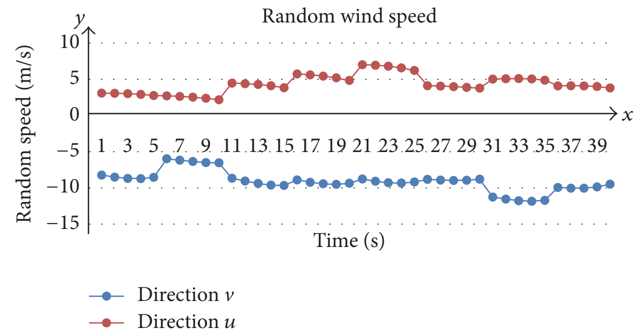

Figure 2: Random wind component chart.

In this study, four models of rescue aircraft were used: M-171, M-8, Y7-100, and Y5-B(K).

The performance parameters of the different aircraft models are listed in Table 3.

The forecasted random wind data at the coordinates of the switching station were calculated with the hexahedral interpolation model [21] and are shown in Table 4. The corresponding random wind component chart and the resultant random wind velocity chart are displayed in Figures 2 and 3, respectively.

4.2. Results and Analysis. The proposed model was solved using Lingo. The aircraft scheduling results and distribution routes are shown in Table 5. The total mileage of the entire transport network under this aircraft scheduling plan is 6220.8 km. The allocations of relief supplies are shown in Table 6. The corresponding average supply satisfaction is 95.2%, which is the optimum of the objective function.

As shown in Tables 5 and 6, all devastated points are divided into three groups and receive relief supplies from different rescue points. Aircrafts are distributed according to the different relief supply demands of different devastated points. For example, Y-100 takes off from rescue point 1 and follows the route of 1-5-4-1 (green route at the top part of Figure 4). Its mileage of transport is 646.5 km. This aircraft sends 1,200 kg durable goods and 600 kg fast-moving consumer goods to region 5, as well as 1,400 kg durable goods and 800 kg fast-moving consumer goods to region 4.

According to the optimal solutions calculated by Lingo, the routes of rescue point 2 change when the same grouping of devastated points and application of aircraft was applied. For example, the route of Y5-B(K) changes from 2-13-2 to 2-13-12-2, causing 168.4 km additional mileage of transport. The route of M-171 changes from 2-17-16-2 to 2-10-16-2, thereby increasing the mileage of transport by 118.8 km. The route of

Table 2: Demands of devastated points.

Number	Name	Rescue priority	Demands /(kg)		Minimum demands /(kg)	
			D_i^0	D_i^1	LD_i^0	LD_i^1
4	Hongbai Town	4	1400	800	1000	500
5	Qiandi Town	5	1700	1100	1200	600
6	Luoshui Town	4	900	700	600	400
7	Mazu Town	2	600	500	300	300
8	Louqiao Town	1	800	500	600	300
9	Qiaozhuang Town	3	1100	900	800	600
10	Qingxi Town	3	1100	900	700	700
11	Quhe Town	4	1600	800	1300	500
12	Shazhou Town	1	400	300	300	200
13	Suhe Town	5	900	600	600	400
14	Wali Town	1	400	400	200	300
15	Yaodu Town	3	1300	800	800	600
16	Sanguo Town	2	900	600	600	400
17	Yuexi Town	4	1300	1000	1000	600
18	Kangding Town	2	1200	700	900	500
19	Yongshan Town	2	1300	1100	1000	800
20	Ludian Town	2	1100	600	700	300
21	Jinggu Town	4	700	700	500	400

Table 3: Performance parameters of aircraft models.

Type	Maximum amount of fuel/(kg)	Average fuel consumption rate/(kg)	Average speed/(km/h)	Maximum payload/(kg)	Maximum climb rate/(m/s)	Ceiling/(m)
M171	2732	420	230	4000	9.3	10675
M8	2027	310	180	2900	7.7	6520
Y7-100	4790	690	423	5500	7.6	8750
Y5-B(K)	900	250	190	1500	8.3	4500

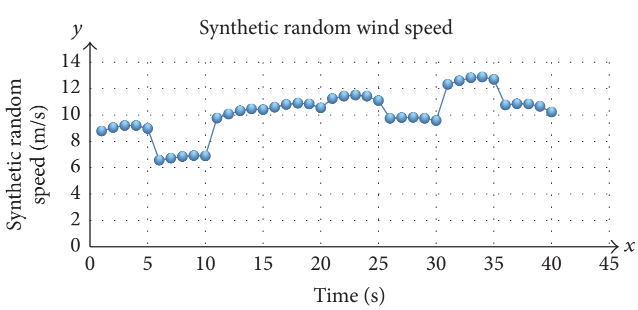

Figure 3: Resultant random wind velocity chart.

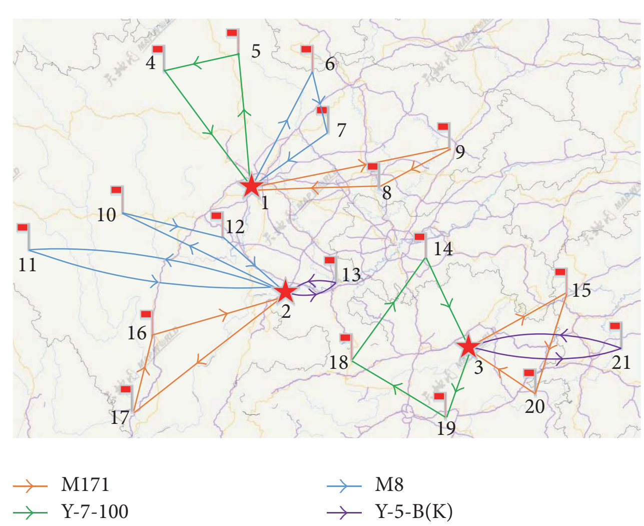

Figure 4: Decision on emergency aircraft scheduling plan for Wenchuan earthquake disaster region calculated by Lingo.

M-8 becomes 2-17-2 and 2-11-2 rather than 2-10-12-2 and 2-1-2, thereby increasing the mileage of transport by 113.3 km. The total mileage of transport of aircraft taking off from rescue point 2 is 2,848.7 km. This value is 400.5 km greater than that of the optimal solution of Lingo.

In this study, aircraft scheduling plans with or without influences of random wind were discussed. Through the data analysis based on Table 2, random wind obeys $v_{\text{wind}} \sim N(-10.146, 0.293)$. For example, Y-100 follows the route of 1-5-4-1 (green route at the top part of Figure 4), and its average flight speed is 423 km/h. Thus, the sum velocity of

Table 4: Forecasted wind vector value at the switching station.

Number	Component u/(km/h)	Component v/(km/h)	Wind direction (°)
1	−8.22109	3.096002	178.7894
2	−8.50132	3.074244	178.7762
3	−8.68536	3.026139	178.7645
4	−8.71515	2.927397	178.7533
5	−8.54335	2.760375	178.7417
6	−5.96725	2.726115	178.8577
7	−6.17387	2.646679	178.8342
8	−6.35687	2.53235	178.8083
9	−6.48779	2.377908	178.7805
10	−6.53854	2.184142	178.7516
11	−8.66544	4.476649	178.9061
12	−9.04453	4.410188	178.8829
13	−9.38519	4.293882	178.8583
14	−9.61591	4.110244	178.8331
15	−9.66666	3.849385	178.8082
16	−8.89341	5.754836	179.0035
17	−9.2132	5.625553	178.9774
18	−9.43946	5.451726	178.9529
19	−9.50738	5.202419	178.9299
20	−9.36043	4.854606	178.9076
21	−8.77416	7.033259	179.1049
22	−9.07299	6.957304	179.0834
23	−9.27875	6.821929	179.0632
24	−9.33216	6.588525	179.0439
25	−9.18085	6.227895	179.0253
26	−8.82292	4.129391	178.8669
27	−8.91456	4.06918	178.8574
28	−8.96513	3.996232	178.8485
29	−8.93809	3.901841	178.8408
30	−8.79882	3.778968	178.8349
31	−11.2607	5.024794	178.8489
32	−11.5372	5.091888	178.8448
33	−11.7602	5.108503	178.8390
34	−11.8469	5.049638	178.8321
35	−11.7181	4.894799	178.8249
36	−9.93732	4.09711	178.8203
37	−10.0377	4.127017	178.8193
38	−10.0365	4.106525	178.8176
39	−9.86863	4.007229	178.8149
40	−9.48224	3.810378	178.8113

the random wind speed and true airplane airspeed obeys $v_{mk} \sim N(415.193, 0.314)$. When selecting 100 random wind test points from this route ($H = 100$), the average airplane flight speed in this route is 414.096 km/h, and the transport time with random wind is 1.558 h by means of Constraint (20). Accordingly, the other transport times of every route can be calculated. The corresponding transport times are shown in Table 7.

In Table 7, the total transport time without random wind is 27.015 h, and the total transport time with random wind is 29.530 h. Therefore, the total delay time caused by random wind is 2.515 h, and the average delay time of aircraft from different rescue points is 0.838 h.

To ensure the validity of the proposed model, we quantitatively analyzed the model in [9] and the proposed aircraft scheduling model using the data in Section 4.1 and two evaluation standards (total transport time $\overline{\mathrm{AT}}$ and supply satisfaction $\overline{\mathrm{AF}}$). The results are shown in Table 8.

Table 8 shows that the proposed aircraft scheduling model is superior to the emergency logistics distribution model in [9]. The reason is that the proposed model achieves 9.82% higher supply satisfaction, although its total transport time is 2.515 h longer because of the consideration of the delay caused by a crosswind-induced longer flight path. The proposed model is highly applicable to actual aircraft rescues.

5. Conclusion

Flight route is as important as rescue priority in aircraft-aided rescue operations. Flight route is related to rescue efficiency and can exert a significant influence on rescue safety, especially in regions with complex meteorological conditions and frequent occurrences of natural disasters. Considering the practical scheduling problem of aircraft emergency rescue at present, a multiobjective model is established in this study. The model is calculated using Lingo. Finally, the transport times of aircraft with and without the influence of random wind are analyzed on the basis of the data of an earthquake disaster area. The proposed model is compared with the emergency logistics distribution model in [9], and the results confirm that the proposed model is more feasible and applicable to practical situations.

(1) Prioritizing the objective function of supply satisfaction while maintaining maximum rescue priority satisfaction during the dispatching of emergency resources can considerably reduce unnecessary economic losses, thus improving the integrated dispatching efficiency. The proposed model reduces economic cost indirectly through the reasonable allocation of relief supplies and planning of the shortest route.

(2) Scheduling time is important during emergency rescue. In this study, we focus on the shortest route planning and aircraft scheduling based on rescue priority to shorten the rescue time indirectly.

(3) The data involved in the proposed model can be adjusted according to a specific problem. Rescue priority and supply demands can be set according to disaster prediction information on different regions, thus enhancing the rescuing effect.

Nevertheless, there is still a great potential for improving the authenticity and effectiveness of the optimization model.

(1) Random wind on flight track is considered in this study, and the influence of multiple complicated

Table 5: Decision on aircraft emergency scheduling plan calculated by Lingo.

	Devastated point in the group	Type	Route	Mileage/(km)	Total mileage/(km)
Rescue point 1	4, 5, 6, 7, 8, 9	Y7-100	1-5-4-1	646.5	1870.9
		M-171	1-9-8-1	697.0	
		M-8	1-6-7-1	527.4	
Rescue point 2	10, 11, 12, 13, 16, 17	Y5-B(K)	2-13-2	164.4	2448.2
		M-171	2-17-16-2	772.4	
		M-8(two)	2-10-12-2	626.5	
			2-11-2	884.9	
Rescue point 3	14, 15, 18, 19, 20, 21	Y7-100	3-19-18-14-3	778.9	1901.7
		Y5-B(K)	3-21-3	544.4	
		M-171	3-15-20-3	578.4	

Table 6: Relief supply allocation calculated by Lingo.

Rescue point	Devastated point	X_i^0/(kg)	X_i^1/(kg)	Relief supply satisfaction
Area 1	Area 4	1400	800	93.80%
	Area 5	1200	600	
	Area 6	900	700	
	Area 7	600	500	
	Area 8	800	500	
	Area 9	1100	900	
Area 2	Area 10	1100	1000	94.10%
	Area 11	1400	500	
	Area 12	400	300	
	Area 13	900	600	
	Area 16	900	600	
	Area 17	1300	1000	
Area 3	Area 14	400	400	97.70%
	Area 15	1300	800	
	Area 18	1200	700	
	Area 19	1300	800	
	Area 20	1100	600	
	Area 21	700	700	

Table 7: Transport times with and without random wind.

	Transport times without random wind/(h)	Total transport times without random wind/(h)	Transport times with random wind/(h)	Total transport times with random wind/(h)
Area 1	1.528	7.488	1.558	7.733
	3.03		3.126	
	2.93		3.049	
Area 2	0.865	12.619	1.233	14.335
	3.358		3.964	
	8.396		9.138	
Area 3	1.528	6.908	1.877	7.462
	2.865		2.991	
	2.515		2.594	

Table 8: Comparison of performance parameters of two models.

	$\overline{\text{AT}}$	$\overline{\text{AF}}$
Proposed model	29.530 h	95.98%
Model in [9]	27.015 h	87.40%
Upgrade rate	−9.31%	+9.82%

weather conditions on aircraft scheduling is ignored. In the next step, the influence of some special weather conditions, such as thunderstorm and dense fog, could be add into the constraints.

(2) The course angle of aircraft was equal to track angle in the optimization model, and the flight route planning is simplified. In order to fit the actual flight scene more, flight process can be more refined in future research.

(3) We provided initial disaster data for the optimization model in this paper. Real-time and accurate information of survivals and materials in traffic networks is needed to be acquired in the future.

(4) In future studies on aircraft scheduling, we can combine flight conflict detect and conflict resolution, as well as a barrier-overcoming flight strategy, to develop highly accurate flight plans on the basis of flight route and to increase the accuracy of rescue dispatching. It will have a high theoretical value and practical significance.

Notations

Model Indices

g: Group set of devastated points
m: Rescue point m, $m = 1, \ldots, M$
k: kth aircraft, $k = 1, \ldots, K$
l: Type of relief supplies, $l = 0$ represents durable goods, and $l = 1$ represents fast-moving consumer goods
j: jth flight path.

Model Constants

M: Total number of rescue points
K: Total number of aircraft
N: Total number of devastated points.

Model Variables

L_m: Number of devastated points aided by rescue point m
H_j: Number of random wind test points in the jth route
Q_{mk}: Maximum payload of the kth aircraft at rescue point m
f_{mk}: Maximum fuel load of the kth aircraft at rescue point m
c_{mk}: Average fuel consumption rate of the kth aircraft at rescue point m
i_g: Devastated point i in group g
W_{ig}: Rescue priority of devastated point i in group g, $W_{ig} = 1, \ldots, 5$
$D_{ig}^l(t)$: Time-varying demands for material l of devastated point i in group g in the given time interval t
$\mathrm{LD}_{ig}^l(t)$: Minimum time-varying demands for material l of devastated point i in group g in the given time interval t
$S_{ig}^l(t)$: Time-varying supply of material l of devastated point i in group g in the given time interval t
$X_{m,ig}^l(t)$: Weight of material l delivered from rescue point m to devastated point i in group g in the given time interval t
n_{mk}: Number of devastated points served by the kth aircraft from rescue point m
r_{mji}: Order of devastated point i in the routes from rescue point m
$d_{r_{mj(i-1)} r_{mki}}$: Distance between devastated points
$d_{r_{mjn_{mk}} r_{mj0}}$: Distance between the rescue point and the devastated point
$\mathrm{sign}(n_{mk})$: On-off variable, representing whether the kth aircraft from rescue point m passes through the point
$\bar{v}_{mk}$: Average flight speed of the kth aircraft at rescue point m, which is the vectorial sum of u_{GS} and v_{GS}
v_{mk}: Actual flight speed of kth aircraft at rescue point m.

Competing Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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