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Multi-resource Scheduling Problem for Emergency Supplies Based on Improved Sparrow Search Algorithm

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Abstract

In order to address the issue of the dispatch of supplies following a major public health event, this paper considers the use of multiple means of transport for the joint movement of materials, a three-tier dispatch network with multiple supply points, multiple distribution centres and multiple demand points is used to achieve multi-cycle, multi-modal and multi-resource dispatch of emergency supplies, with timeliness, dual fairness and comprehensive costs as the objectives. This paper takes the disaster relief demand after a major public health event as the research object, and establishes a multi-objective optimal scheduling model for emergency materials around the problem of emergency relief materials scheduling in disaster areas, good point sets, dynamic inertia weights, polynomial variants and greedy selection strategies are introduced to improve the sparrow algorithm and solve the model. The results show that the improved sparrow algorithm can consistently find the optimal value of the function in a wide range of test functions. Compared with the original algorithm and the grey wolf algorithm, the convergence accuracy is higher, the solution performance is superior, and a more efficient and fair scheduling scheme can be obtained to solve the multimodal and multi-cycle emergency material scheduling problem. As a result, the improved sparrow search algorithm performs well in dealing with more complex emergency material scheduling and demonstrates its significant value and effectiveness in practical applications.

Keywords: Major public health incidents, emergency supplies dispatching, multimodal transport, improved sparrow search algorithm.

1. Introduction

In recent years, public health emergencies have occurred frequently, bringing huge economic losses and casualties to China. The occurrence of the incident will generate a huge number of material demand, while the material distribution centre and the material reserve at the demand point are usually difficult to meet the material demand. Therefore, it has become an urgent problem to be solved by constructing an emergency material dispatching model to realise the material distribution after the emergencies.

In 1984, Kemball et al.[1] systematically introduced the process of Somali refugee relief and lessons learnt, and put forward the concept of emergency material dispatch for the first time, and scholars at home and abroad have carried out research in this regard in full swing. In the construction of material dispatching model, scholars take economy[2] timeliness[3] fairness[4] and disaster victims' satisfaction[5] and disaster victims' satisfaction as the objectives, and construct single-objective or multi-objective models. Zhang et al.[6] used triangular fuzzy numbers to transform uncertainties and constructed a material dispatching model with multiple demand points by taking timeliness and economy as the objectives; Wan et al[7]. Based on the real disaster road network, a dispatching model considering the orderly arrival of materials is constructed and verified by using a real landslide disaster case; Hao et al.[8] using triangular fuzzy numbers to describe the demand and distribution time of materials to construct a multi-objective model with minimum cost and minimum distribution delay time.

In terms of dispatching resource types, Zhang et al.[9] consider the limited rationality of human beings to determine the satisfaction of the affected population with the dispatch time and the quantity of materials obtained, and use this as a basis to establish a dispatch model for a single type of material. With the deepening of the research, scholars gradually realised that it is difficult to cope with the real post-disaster emergency situation by only involving a single type of resources for material dispatch. Liu et al.[10] constructed a multi-objective model for emergency supplies that includes multiple resources, and designed a co-evolutionary multi-population particle swarm algorithm, which uses two populations to optimise the objectives separately, and obtains the Pareto-optimal solution; Li et al.[11] Considering the frequent occurrence of terrorist attacks and the need to dispatch multiple resources from multiple regions, a multi-objective model is constructed and an improved particle swarm-cuckoo algorithm is designed to solve the problem; Zhang et al[12]. Used integer mathematical programming to model the multi-resource and multi-emergency response problem considering multiple natural disasters, and designed a heuristic algorithm to solve it efficiently.

In terms of the composition of the dispatch network, Liu et al.[13]. Designed an allocation mechanism under fuzzy demand, and determined the relationship between uncertainty and contingency cost to help decision makers better deal with the distribution of materials in the secondary dispatch network under emergency situations, and Wang et al.[14]. From the perspective of disaster victims, a multi-objective scheduling model is constructed based on minimising the degree of unsatisfiedness and minimising the cost by taking into account the situation of oversupply of materials and mutual aid of disaster victims. All of the above literatures use one-time scheduling, which does not take into account the continuity of emergencies and the subsequent updating of materials, and Huang et al.[15] constructed a multi-cycle material scheduling model considering time window and staged delivery; Yanyan Wang et al.[16] considering that single-stage material scheduling has problems such as low efficiency of material transfer, and incorporating the index effect to measure the fairness of material scheduling, a multi-stage and multi-objective material scheduling model is constructed; Zhu and Wang[17]. In order to improve the satisfaction of disaster victims with the material dispatch programme, a material dispatching model is constructed with the objective of the victims' satisfaction with the material demand and the material delivery time, which improves the satisfaction of the victims and guarantees the reasonable allocation of resources.

In terms of the use of transport means, Shen et al.[18] constructed a demand-splittable emergency material dispatch model with the objective of minimising the distance of material transport and emergency cost; Xia Zhang et al[19]. Considered a material dispatch model under flooding with the degree of material demand, rescue cost and transport risk as the objectives; all of the above literatures used a single means of transport to dispatch the materials without considering the emergencies in terms of road constraints. Yan and Xu[20] took the oil spill accident as an application scenario, constructed a multi-objective scheduling model including multiple resources and intermodal transport, and used an improved genetic-ant colony optimisation algorithm to solve the problem; Li et al.[21] constructed a dispatching network with multimodal and hub-and-spoke structures, and constructed a material dispatching model with the objectives of minimising transport time and minimising cost; Zhang et al.[22] considering the joint distribution mode of multiple means of transport, a dynamic scheduling model containing a multilevel scheduling network is constructed with the objective of minimising the rescue cost, rescue time and the psychological cost of drivers.

Analysing the findings of the relevant literature, it is found that there are still some difficulties to be solved with regard to the scheduling of emergency medical supplies after the occurrence of a major public health event. First of all, most of the sudden disaster events require long-term material supply, and the material demand of each demand point is constantly changing, so it is necessary to implement multi-cycle material scheduling; secondly, emergency material scheduling often involves a variety of resources, and a single type of resource scheduling is not close to the actual situation; once again, most of the current literature adopts the same means of transport, which is prone to have a big difference with the actual situation. Based on the above problems, this paper adopts the following solutions:

(1) Considering the suddenness and continuity of health events, build a dispatch network with multiple supply points, multiple distribution centres and multiple demand points to achieve multi-cycle, multi-resource and multi-modal dispatch of materials.

(2) In order to address the challenges of dispatching supplies after a major public health event, the goal is to maximise timeliness, maximise dual equity and minimise overall costs, taking into account the satisfaction of the affected population and the economic costs.

(3) Aiming at the shortcomings of the standard sparrow algorithm, such as poor initial quality and easy to fall into local optimum, we design the improved sparrow algorithm which integrates the good point set strategy, dynamic inertia weight, polynomial variation and greedy selection strategy, and use the test function to verify the superiority of the improved algorithm.

2. Description of the Problem

In order to solve the problem of difficult cross-regional scheduling of emergency supplies, this paper establishes a multimodal supply point, multidistribution centre and multidemand point dispatch model. Considering that most emergencies have a long duration and far-reaching impact, this paper divides the supplies dispatch into multiple cycles, and achieves the multimodal multi-cycle and multi-objective scheduling of emergency supplies with the goals of minimizing the transport time, maximizing the double fairness, and minimizing the comprehensive rescue cost. In this paper, the scheduling of emergency materials is divided into multiple cycles with the goal of minimising transport time, maximising double fairness and minimising comprehensive rescue cost.

3. Modelling

3.1 Model assumptions

(1) The material requirements at each demand point are known.

(2) The amount of material available at each supply point and distribution centre is known.

(3) The warehouses of the supply points and distribution centres are capable of holding the materials received.

(4) The distances between the supply point, the distribution centre and the demand point are known and each means of transport maintains a constant speed.

3.2 Description of model variable symbols

The distribution network $\mathrm{G}=\{\mathrm{A}, E\}$ contain q supply points, p centres of distribution and n points of demand.

$Q=\{q \mid q=1,2,\ldots,Q\}$ is the set of supply points q ;

$P=\{p \mid p=1,2,\ldots,P\}$ is the set of distribution centres p ;

$N=\{n \mid n=1,2,\ldots,N\}$ is the set of demand points n ;

$T=\{t \mid t=1,2,\ldots,T\}$ is the set of cycles t ;

$K=\{k \mid k=1,2,\ldots,K\}$ is a collection of material types k ;

$W=\{w \mid w=1,2,\ldots,W\}$ is a collection of transport modes;

V_w :The speed at which materials are transported by means of transport w ;

D_p^q :Distance from supply point q to distribution centre p ;

D_n^p :Distance from the distribution centre p to the demand point n ;

σ :Minimum material assigned amount coverage at the point of need;

c_w :Fixed transport costs of transporting materials by means of transport w ;

c_w' :The unit transport cost of transporting materials by means of transport w ;

x_{nk}^t :Demand point n Demand for material k in the first t cycle;

g_{qpk}^{tw} :The actual volume of material k transported by the supply point q to the distribution centre p via the mode of transport w during the t cycle;

g_{pnk}^{tw} :The actual volume of material k transported by the distribution centre p to the demand point n via the mode of transport w during the t cycle;

S_{qpk}^t :Maximum supply of materials k from supply point q to distribution centre p in cycle t ;

S_{pnk}^{tw} :Maximum supply of materials k from the distribution centre p to the demand point n in cycle t ;

$K_{qk}^{t\,\prime}$:Quantity of material k obtained at supply point q in cycle t ;

K_{pk}^t :The remaining inventory of p supplies k in the distribution centre at the end of cycle t ;

K_{qk}^t :Remaining stock of the material k at the supply point q at the end of cycle t ;

D_{nk}^t :Shortage of n material k at the point of need at the end of cycle t ;

x_{qp}^{tw} :Weekly Supply Points q Whether emergency supplies are transported to the Distribution Centre p by transport w ;

y_{pn}^{tw} :Cycle t Distribution Centre p Whether the emergency supplies are transported to the demand point n by transport w .

3.3 Objective function

(1) Timeliness function

After the occurrence of a public health event, medical supplies should be sent to each demand point in time to stop the spread of the disaster. Therefore, this paper constructs the timeliness function, as shown in Eq.(3), the shorter the transport time of materials, the greater the timeliness, indicating that the material scheduling process is reasonable and effective, and can meet the material demand of the place where the public health event occurs in time.

$$T_n^t = \left\{ \sum_{w=1}^{W} x_{qp}^{tw} \frac{D_p^q}{v_w} + \sum_{w=1}^{W} y_{pn}^{tw} \frac{D_n^p}{v_w} \mid q \in Q, p \in P, n \in N, t \in T \right\} \tag{1}$$

$$T^t = \max\{T_n^t, n \in N, t \in T\} \tag{2}$$

$$Z_1 = \sum_{t=1}^{T} T_t \tag{3}$$

Where, T_n^t indicates the time of delivery of demand point material for demand point n in cycle t, T^t indicates the time when all demand points are supplied in cycle t, which is the actual maximum rescue time, and Z_1 indicates the sum of the total rescue time in each cycle.

(2) Dual fairness function

The fairness objective, as a common objective in the construction of material dispatching model, is used to indicate the reasonableness of the material dispatching scheme.Unfair material dispatching is very likely to cause panic and dissatisfaction of the disaster victims, which is easy to cause unrest in the disaster area, and the reasonable material dispatching scheme is conducive to maintaining the order of the disaster area, helping more victims to get out of trouble as soon as possible, and returning the society to the right track. Therefore, this paper takes the fairness of material distribution and the fairness of material arrival time as the important factors, constructs the double fairness function, and helps to obtain the reasonable and fair material dispatching programme.

a) Material Distribution Equity Function

The material demand of each demand point is different, and the amount of materials that can be obtained is not consistent, in the event of a disaster, the victims are extremely sensitive to the fairness of material distribution, when the fairness of material distribution is insufficient, it is easy to cause dissatisfaction among the victims, which is not conducive to the effective advancement of the rescue operation. Therefore, this paper constructs the fairness function of material distribution, as shown in Eq.(7).

$$\rho_{nk}^t = \frac{\sum_{p=1}^{P} g_{pnk}^{tw} y_{pn}^{tw}}{x_{nk}^t} \tag{4}$$

$$\overline{\rho_{nk}^t} = \frac{\sum_{n=1}^{N} \rho_{nk}^t}{N} \tag{5}$$

$$n_k^t = \frac{\sum_{n=1}^{N} \left(\rho_{nk}^t - \overline{\rho_{nk}^t}\right)^2}{N-1} \tag{6}$$

$$F_1 = \sum_{t=1}^{T} \sum_{k=1}^{K} \eta_k^t \tag{7}$$

Where ρ_{nk}^t denotes the rate of the satisfaction of demand at demand point n for material k in cycle t, $\overline{\rho_{nk}^t}$ denotes the average material demand fulfilment rate, η_k^t denotes the variance of the rate of fulfilment of the demand for material k in cycle t, and F_1 denotes the material distribution fairness function.

b) Material arrival time fairness function

The distance between the demand point and the supply point and the distribution centre is different, then the material delivery arrival time is different, try to reduce the variability of the material arrival time, is conducive to improving the fairness of the material arrival time. Therefore, this paper constructs the material arrival time fairness function, as shown in Eq.(9).

$$M_n^{t'} = T_n^t - \min\left(T_n^t\right) \tag{8}$$

$$F_2 = \sum_{n=1}^{N}\sum_{t=1}^{T} M_n^{t'} \tag{9}$$

where $M_n^{t'}$ denotes the difference between the demand point n and the demand point with the smallest material arrival time at cycle t ,and F_2 denotes the material arrival time fairness function.

Therefore, the double fairness function after a major public health event is shown in Eq.(10).

$$Z_2 = F_1 + F_2 \tag{10}$$

(3) Cost function

After the occurrence of a major public health event, a large amount of material supply and financial support is needed to carry out rescue operations, therefore, this paper constructs a cost function with fixed transport cost and actual transport cost as the components, as shown in Eq.(13).

$$C_1 = \sum_{q=1}^{Q}\sum_{p=1}^{P}\sum_{t=1}^{T} c_w x_{qp}^{tw} + \sum_{q=1}^{Q}\sum_{p=1}^{P}\sum_{t=1}^{T} c_w y_{pn}^{tw} \tag{11}$$

$$C_2 = \sum_{q=1}^{Q}\sum_{p=1}^{P}\sum_{t=1}^{T} c_w{}' g_{qpk}^{tw} x_{qp}^{tw} + \sum_{p=1}^{P}\sum_{n=1}^{N}\sum_{t=1}^{T} c_w{}' g_{pnk}^{tw} y_{pn}^{tw} \tag{12}$$

$$Z_3 = C_1 + C_2 \tag{13}$$

Where C_1 is the fixed transport cost, C_2 is the actual transport cost,and Z_3 is the integrated cost function.

3.4 Mathematical modelling

Based on the specific analysis of the objective function above, the multi-objective emergency material scheduling model is constructed as follows:

$$\min Z_1 = \sum_{t=1}^{T} T^t \tag{14}$$

$$\min Z_2 = F_1 + F_2 \tag{15}$$

$$\min Z_3 = C_1 + C_2 \tag{16}$$

s.t.

$$\sum_{w=1}^{W}\sum_{p=1}^{P} g_{qpk}^{tw} x_{qp}^{tw} \le S_{qpk}^{t}, \forall t \in T, q \in Q, k \in K \tag{17}$$

$$\sum_{n=1}^{N} g_{pnk}^{tw} y_{pn}^{tw} \le S_{pnk}^{t}, \forall t \in T, p \in P, k \in K \tag{18}$$

$$\sigma x_{nk}^{t} \leq \sum_{p=1}^{P} g_{pnk}^{tw} \leq x_{nk}^{t}, \forall t \in T, n \in N, k \in K \tag{19}$$

$$\sum_{w=1}^{W}\sum_{q=1}^{Q} g_{qpk}^{tw} + K_{pk}^{t-1} = \sum_{w=1}^{W}\sum_{n=1}^{N} g_{pnk}^{tw} + K_{pk}^{t}, \quad \forall t \in T, p \in P, k \in K \tag{20}$$

$$\sum_{w=1}^{W}\sum_{p=1}^{P} g_{pnk}^{tw} + D_{nk}^{t} = x_{nk}^{t} + D_{nk}^{t-1}, \quad \forall t \in T, n \in N, k \in K \tag{21}$$

$$K_{qk}^{t\,\prime} + K_{qk}^{t-1} = \sum_{w=1}^{W}\sum_{p=1}^{P} g_{qpk}^{t} + K_{qk}^{t}, \quad \forall t \in T, q \in Q, k \in K \tag{22}$$

$$x_{qp}^{tw} \in \{0,1\}, y_{pn}^{tw} \in \{0,1\} \tag{23}$$

$$g_{qpk}^{tw} \geq 0, g_{pnk}^{tw} \geq 0, D_{nk}^{t} \geq 0, \forall t \in T, \quad q \in Q, p \in P, n \in N, k \in K, w \in W \tag{24}$$

where Eq.(14) denotes the minimisation of rescue time; Eq.(15) denotes the maximisation of the fairness of material dispatch; Eq.(16) denotes the minimisation of rescue cost; Eq.(17) and (18) denotes the maximum capacity constraint of supply point and distribution centre; Eq.(19) denotes that the actual quantity of materials obtained by each demand point is not greater than the quantity of materials demanded and meets the minimum material guarantee; Eq.(20) - (22)denotes the the balance of material quantities at the point of demand, the distribution centre and the point of supply; Eq.(23) denotes the 0-1 constraint of decision variables; Eq.(24) indicates that the quantity of supplies should be non-negative.

4. Algorithm Solving

4.1 Standard sparrow search algorithm

(1) Introduction to the algorithm

Sparrows are commonly dispersed birds that can be seen in everyday situations and in groups. Within a sparrow population, different types of sparrows possess different behavioural habits. In general, they can be summarised into two types: finders and followers. Discoverer sparrows are more capable of efficiently finding enough food for themselves, but follower sparrows have a limited ability to forage on their own, and therefore need to follow the discoverer in search of food or compete with the discoverer. Studies have shown that the distinction between finder and follower sparrows is based on the amount of food available; if there is not enough food, the sparrow will behave as a follower and if there is enough food, the sparrow will behave as a finder. While searching for food, sparrows are usually extremely attentive to their surroundings and will continue to feed when they think it is safe to do so, but if they perceive danger, they will immediately fly away and travel en masse to another area to search for food again. Sparrows will also constantly change their position in the population to increase their safety.

(2) Mathematical Modelling

To describe the sparrow foraging process, assume that n is the number of sparrows and d is the dimension of the variable to be optimised, then the matrix X is the location of the sparrows as shown in Eq.(25).

$$X = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,d} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,d} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n,1} & x_{n,2} & \cdots & x_{n,d} \end{bmatrix} \tag{25}$$

The fitness value of individual sparrows is shown in Eq.(26), and based on the fitness value, the sparrow population is classified into finders and followers.

$$F_x = \begin{bmatrix} f_1 \\ f_2 \\ \cdots \\ f_n \end{bmatrix} \tag{26}$$

The discoverer possesses a better fitness value than the follower, and its position update formula is shown in Eq.(27).

$$X_{i,j}(t+1) = \begin{cases} X_{i,j}(t) \cdot \exp(\frac{-i}{\alpha \cdot Gen}), if R < ST \\ X_{i,j}(t) + QL \qquad\qquad\qquad , else \end{cases} \tag{27}$$

Among them, t is the current iteration number, Gen is the maximum iteration number, $X_{i,j}(t)$ is the position of the i sparrow in the j dimension at the t iteration, $\alpha(0,1]$ is a random number, Q is a random number obeying the standard normal distribution, L is a matrix at $1*d$, where the elements are all 1, $R \in [0,1]$ is a random number indicating the alarm value of the sparrow encountering the danger, and ST is the safety value of the sparrow facing the danger. $R < ST$ is the alarm value of the current danger to the sparrow population is below the safety value, the population is in a safe condition, and the discoverer can extend the search range and start the search; otherwise, the population is in a dangerous situation, and the discoverer should lead the followers to search for food again.

There are two behaviours of the follower: following the finder who searches for more food to find or compete for food, and the follower's position update formula is shown in Eq.(28).

$$X_{i,j}(t+1) = \begin{cases} Q \cdot \exp(\frac{X_w(t) - X_{i,j}(t)}{i^2}), & if i > \frac{n}{2} \\ X_g(t+1) + |X_{i,j}(t) - X_g(t+1)| \cdot A^+ \cdot L, & else \end{cases} \tag{28}$$

where t is the current number of iterations, $X_w(t)$ is the current location of the individual with the worst global fitness value, $X_g(t)$ is the location of the individual with the best fitness value among the discoverers, A is a matrix of $1*d$ with elements 1 or -1, and $A^+ = A^T\left(AA^T\right)^{-1}$.

In the simulation experiment, it is assumed that the individual sparrows present in the population 10%~20% will sense the danger and move to the inner circle, the position is updated in the way as shown in Eq.(29).

$$X_{i,j}(t+1) = \begin{cases} X_b(t) + \beta|X_{i,j}(t) - X_b(t)|, & if f_i > f_b \\ X_{i,j}(t) + K \cdot (\frac{|X_{i,j}(t) - X_w(t)|}{(f_i - f_w) + \varepsilon}), & if f_i = f_b \end{cases} \tag{29}$$

Among them, $X_b(t)$ is the current global optimal solution, β is a step control parameter, which is a random number obeying the standard normal distribution, $K \in [-1,1]$ is a random number indicating the moving direction of the individual sparrow, ε is a constant close to zero, in order to avoid the error that the denominator is 0, f_i is the fitness value of the i sparrow, f_b is the fitness value of the current global optimal solution, and f_w is the fitness value of the current global worst solution. If $f_i > f_b$, the individual sparrow will move towards the globally optimal position; if $f_i = f_b$, it means that the sparrow in the middle position is aware of the danger and will move towards the position close to other individuals.

(3) Algorithmic steps

Step 1: Set parameters such as population number N , alarm value R , safety value ST to initialise the population and get the initial position of each individual.

Step 2: Individual fitness values are calculated to divide the population.

Step 3: According to Eq.(27) update the location of the finder.

Step 4: According to Eq.(28) update the position of the follower.

Step 5: Randomly select the individuals who feel the danger by the set ratio and according to Eq.(29) update its position.

Step 6: Recalculate the fitness values of the individuals of the population and determine the location of the optimal individual.

Step 7: Determine whether the maximum number of iterations has been reached, if so go to the next step, if not go to step 3.

Step 8: Output the optimal result and the algorithm ends.

(4) Algorithm flowchart

According to the steps of the algorithm, the flowchart of the sparrow search algorithm is shown in Figure 1.

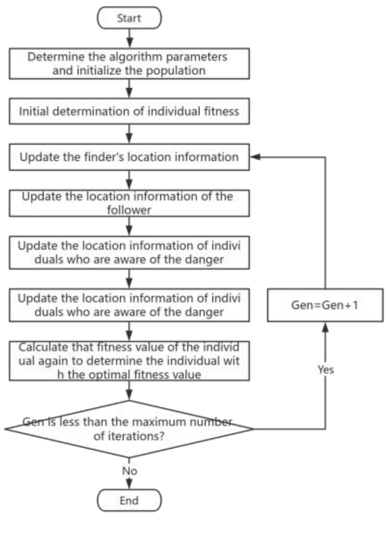


Figure 1 Standard sparrow search algorithm flowchart

4.2 Improvement of sparrow search algorithm

(1) Initialisation of the population of a good point set

When performing population initialisation, Sparrow Search Algorithm (SSA) is prone to lead to uneven distribution of the population if it is affected by random factors. Through the good point set strategy[23] population initialisation can effectively deal with the high-dimensional problem and obtain the initial population with uniform distribution of individuals. Therefore, this paper introduces the good point set strategy to initialise the population with uniform population individuals.

Let G_D be the unit cube of the D dimensional Euclidean space, $r \in G_D$, $P_n(k) = \left(\left\{r_1^{(n)} \cdot k\right\}, \left\{r_2^{(n)} \cdot k\right\}, \ldots, \left\{r_D^{(n)} \cdot k\right\}\right)$, where $1 \le k \le n$, and its deviation $\varphi(n) = C(r, \varepsilon) n^{-1+\varepsilon}$, where $C(r, \varepsilon)$ is a constant associated only with r and ε (ε is an arbitrarily small positive number), then we call $P_n(k)$ the set of good points, and r the set of good points, and n the number of points. In this paper, we take $r = 2\cos\left(\frac{2k\pi}{p}\right), 1 \le k \le D$, where p is the smallest prime number that satisfies $\frac{(p-3)}{2} \ge D$.

(2) Dynamic inertia weights based on hyperbolic tangent functions

The position change of the discoverer in the sparrow population will be close to the global optimal solution from the beginning, which makes the range of the position change of the discoverer too small, causing the problem of low solution accuracy and falling into the local optimum. Therefore, this paperdesigns the inertia weights, as shown in Eq.(30), and add the inertia weights to Eq.(31), so that the discoverer can better perform the global search at the beginning of the iteration and increase the convergence performance of the algorithm when the iteration is near the end.

$$\omega = \frac{e^{2(1-t/T)} - e^{-2(1-t/T)}}{e^{2(1-t/T)} + e^{-2(1-t/T)}} \tag{30}$$

$$X_{i,j}(t+1) = \begin{cases} \omega X_{i,j}(t) \cdot \exp\left(\frac{-i}{\alpha \cdot Gen}\right), if R < ST \\ X_{i,j}(t) + QL \qquad , else \end{cases} \tag{31}$$

Where, ω is the dynamic inertia weight, $X_{i,j}(t+1)$ is the position of thesparrow in the j dimension at the $t+1$ iteration, $\alpha \in (0,1]$ is a random number, Q is a random number obeying a standard normal distribution, L is a matrix of $1*d$ where the elements are all 1, and $R \in [0,1]$ is a random number representing the alarm value of the sparrow encountering danger, ST represents the safety value of the sparrow facing danger.

(3) Polynomial Variation

The sparrow algorithm searches for the optimal value through many iterations, but there is also a risk of falling into the local optimum. Adding the mutation operation can help the algorithm to jump out of the local optimum, improve the algorithm's solution efficiency, and increase the diversity of the population in the late iteration. Therefore, in this paper, we use polynomial mutation to mutate the optimal sparrow individuals in the population, as shown in Eq.(35). Then the greedy selection strategy is used, if the solution after mutation is better than the current optimal solution, the optimal solution is replaced by the mutated solution, so that the algorithm jumps out of the local optimal, and gradually approaches towards the global optimal direction, as shown in Eq.(36).

a) Random number selection Select random number: $u_i \in [0,1)$.

b) Calculate the value of β

$$\beta = \begin{cases} [2u + (1-2u)(1-\delta_1)^{\eta_n+1}]^{\frac{1}{\eta_n+1}-1}, if & u \le 0.5 \\ 1 - [2(1-u) + 2(u-0.5)(1-\delta_2)^{\eta_n+1}]^{\frac{1}{\eta_n+1}}, else & \end{cases} \tag{32}$$

Among them:

$$\delta_1 = \left(X_{i,j}(t) - l\right) / (u - l) \tag{33}$$

$$\delta_2 = \left(u - X_{i,j}(t)\right) / (u - l) \tag{34}$$

where η_n is the distribution index, u is the upper bound of the objective function, and l is the lower bound of the objective function.

$$X_{i,j}(t+1) = X_{i,j}(t) + \beta(u-1) \tag{35}$$

$$X_{best}(t+1) = \begin{cases} X_{best}(t), f(X_{i,j}(t)) > f(X_{best}(t)) \\ X_{i,j}(t+1), else \end{cases} \tag{36}$$

4.3 Algorithm steps and flowchart

(1) Algorithmic steps

Step1:Determine the parameters such as population number N , maximum number of iterations Gen , alarm value R , safety value ST .

Step 2: Initialise the population using good point set theory to determine individual fitness values.

Step 3: Individual sparrow fitness is ranked to determine the location of finders and followers.

Step 4: Using Eq.(31) to calculate the location of the discoverer individual.

Step 5: Using Eq.(28) to calculate the position of the follower individual.

Step 6: Use Eq.(29) to calculate the location of the individual scout.

Step 7: Perturb the current optimal solution using polynomial variation strategy to obtain a new solution.

Step 8: Based on the greedy selection strategy, determine whether to replace the current optimal solution by the mutated solution.

Step 9: Determine whether the maximum number of iterations has been reached, if so go to the next step, if not then go to step 2.

Step 10: Output the optimal result and the algorithm ends.

(2) Algorithm flowchart

According to the steps of the algorithm, the flowchart of the improved sparrow algorithm is shown in Figure 2.

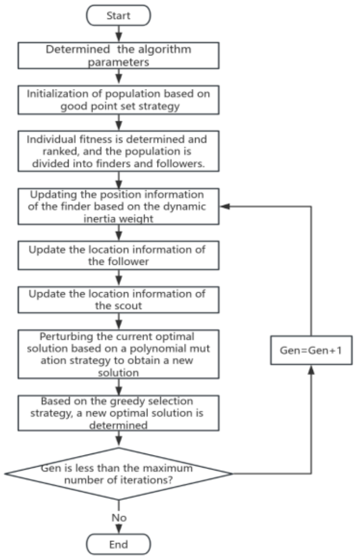


Figure 2 Flow chart of improving sparrow search algorithm

4.4 Algorithm performance analysis

(1) Test Functions

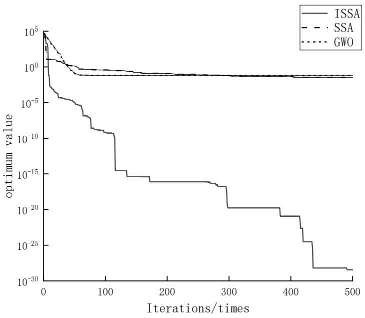
In this paper, six test functions are used to verify the effectiveness of the improved sparrow algorithm, as shown in Table 1.

Table 1 Test functions.

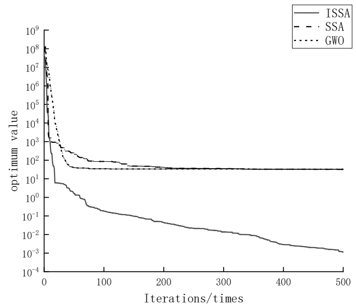
function (math.)	Search Scope
$F_1(x)=\sum_{i=1}^{n} x_i^2$	[-100,100]
$F_2(x)=\sum_{j=1}^{n-1}\left[100\left(x_{j+1}-x_j^2\right)+\left(x_j-1\right)^2\right]$	[-30,30]
$F_3(x)=\sum_{j=1}^{n}\left(\left[x_j+0.5\right]\right)^2$	[-100,100]
$F_4(x)=\sum_{j=1}^{n} ix_j^4+rand[0,1)$	[-1.28,1.28]
$F_5(x)=\sum_{j=1}^{n} -x_j \sin\left(\sqrt{\lvert x_j \rvert}\right)$	[-100,100]
$F_6(x)=\frac{1}{4000}\sum_{j=1}^{n} x_j^2-\prod_{j=1}^{n}\cos\left(\frac{x_j}{\sqrt{j}}\right)+1$	[-600,600]

(2) Analysis of results

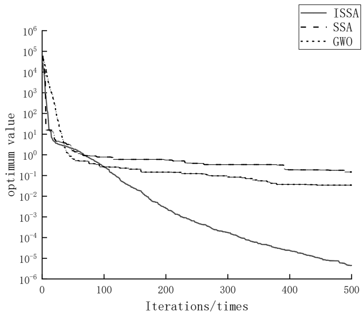
In order to reduce the experimental errors that lead to the deviation of the results, each algorithm is run 30 times to evaluate the running effect of the algorithms. The convergence curves of the algorithms are shown in Figure 3, and the results of the algorithm optimisation comparison experiments are shown in Table 2.



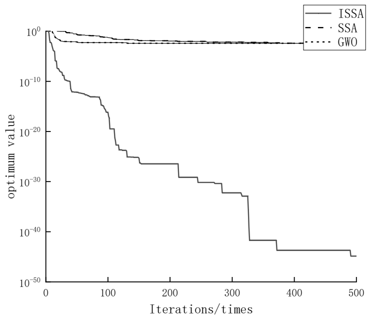
(a) F_1 function iteration diagram



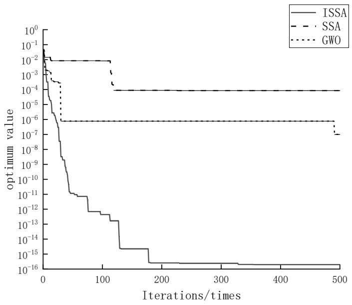
(b) F_2 function iteration diagram



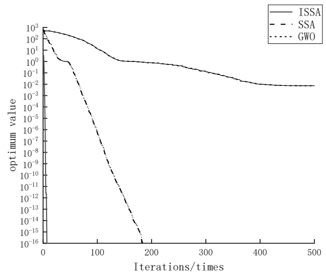
(c) F_3 function iteration diagram



(d) F_4 function iteration diagram



(e) F_5 function iteration diagram



(f) F_6 function iteration diagram

Figure 3 Algorithm convergence curve

From the comparison of experimental results and iteration curves, it can be seen that the Improved Sparrow Search Algorithm (ISSA) algorithm can find the optimal value of the function after many operations of various test functions, indicating that the improved sparrow algorithm in this paper has the effectiveness of solving. By comparing the optimal values, average values and convergence curves obtained by the three algorithms, the ISSA algorithm can find lower optimal values than the SSA algorithm and the GWO algorithm, and it has the ability to jump out of the local optimum, which indicates that the improved sparrow algorithm in this paper has a higher convergence accuracy, and the ISSA algorithm has a more superior convergence performance. By comparing the standard deviation of 30 runs of the three algorithms, it can be obtained that ISSA algorithm has lower running standard deviation, which indicates that ISSA algorithm has superior solution stability than the remaining two algorithms.

Table 2 Comparison of algorithm optimization.

function (math.)	arithmetic	optimum value	average value	(statistics) standard deviation
$F_9(x)$	ISSA	8.22E-59	5.62E-26	1.28E-25
	SSA	2.60E-02	4.03E-02	1.17E-02

	GWO	4.36E-02	5.47E-02	5.42E-03
$F_{10}(x)$	ISSA	1.29E-04	8.26E-03	1.15E-02
	SSA	3.00E+01	3.17E+01	1.05E+00
	GWO	3.14E+01	3.44E+01	2.92E+00
$F_{11}(x)$	ISSA	1.29E-06	3.74E-06	1.08E-06
	SSA	6.15E-02	1.25E-01	2.90E-02
	GWO	2.77E-02	1.94E-01	1.96E-01
$F_{12}(x)$	ISSA	0.00E+00	1.55E-51	6.47E-51
	SSA	5.50E-04	6.74E-03	1.55E-02
	GWO	1.90E-03	3.10E-03	8.15E-04
$F_{13}(x)$	ISSA	2.67E-18	2.25E-06	3.70E-08
	SSA	2.16E-16	1.21E-03	6.36E-07
	GWO	2.87E-16	2.11E-3	6.08E-07
$F_{14}(x)$	ISSA	0	0	2.69E-06
	SSA	0	2.30E-03	9.59E-02
	GWO	0	5.76E-03	2.64E-01

In summary, this paper improves the population initialisation process of the sparrow algorithm by introducing the good point set strategy, which makes the distribution of individuals more uniform; improves the position update formula of the discoverer through dynamic inertia weights, which balances the ability of local and global search; and enhances the ability of the algorithm to jump out of the local optimum through the polynomial variation and greedy selection strategy. After the verification of running results, it shows that the ISSA algorithm designed in this paper has better convergence effect and solution stability than SSA algorithm and GWO algorithm, and the algorithm improvement has effectiveness.

5. Case Studies

5.1 Parameter design

Assuming that a major public health event occurs in a certain place, causing a total of six demand points to be affected, two local transit centres are used as distribution centres, and two adjacent cities are used as supply points to carry out an optimization study on the distribution of materials after the outbreak of the event. The distance from each supply point to the distribution centre is shown in Table 3, the distance from each distribution centre to the demand points is shown in Table 4, the inventory of each cycle at the supply points is shown in Table 5, the demand for materials in each cycle is shown in Table 6, the specific information on the mode of transport is shown in Table 7, and the guaranteed minimum quantity of material distribution at the demand points is $\sigma = 0.55$.

Table 3 Distance from supply point to distribution centre/km.

distribution centre	Distance from supply point to distribution centre	
	q_1	q_2
m_1	437	769
m_2	447	762

Table 4 Distance from distribution centre to demand point/km.

distribution centre	Distance from distribution centre to point of demand					
	n_1	n_2	n_3	n_4	n_5	n_6
m_1	51	50	42	52	65	43
m_2	28	24	32	32	36	59

Table 5 Inventory of materials at supply points in each cycle/kg.

cyclicality	Stock levels at supply points		
	q_1	q_2	add up the total
1	(48000,25000)	(40000,25000)	(88000,50000)
2	(40000,20000)	(45000,30000)	(85000,50000)

3	(30000,25000)	(50000,20000)	(80000,45000)
4	(45000,20000)	(30000,25000)	(75000,45000)
5	(20000,20000)	(45000,15000)	(65000,35000)
6	(20000,10000)	(25000,15000)	(55000,25000)

(Note 1): In the table (20,000,10,000) are the stock levels of protective and anti-personnel supplies, respectively.

Table 6 Demand volume/kg for each cycle of demand point.

demand point	cyclicality					
	1	2	3	4	5	6
n_1	(19957, 11974)	(19837, 11902)	(19407, 11644)	(18097, 10858)	(15611, 9367)	(13239, 7943)
n_2	(17951, 10771)	(17807, 10684)	(17271, 10363)	(15696, 9418)	(13148, 7889)	(11143, 6686)
n_3	(15945, 9567)	(15750, 9450)	(14935, 8961)	(12807, 7684)	(10459, 6275)	(9169, 5501)
n_4	(13957, 8374)	(13843, 8306)	(13450, 8070)	(12359, 7415)	(10545, 6327)	(8992, 5395)
n_5	(11951, 7171)	(11804. 7083)	(11265, 6759)	(9902, 5941)	(8231, 4939)	(7188, 4313)
n_6	(9943, 5966)	(9753, 5852)	(9044, 5426)	(7559, 4535)	(6210, 3726)	(5536, 3322)
add up the total	(89705, 53823)	(88794, 53276)	(85372, 51223)	(76420, 45852)	(64205, 38523)	(55266, 33160)

Note 2): The table (89705,53823) indicates the quantity demanded for protective and extermination supplies respectively.

Table 7 Specific information on transportation modes.

Type of transport	air transport W_1	Road transport W_2
Speed/(km/h)	200	70
Unit transport cost/(yuan/kg)	2	0.5
Fixed transport costs/yuan	40,000	10000

5.2 Analysing the results of the algorithm

In order to verify the effectiveness of the algorithm to solve the model, the model is simulated by Matlab 2018a, and the parameters of the algorithm are set as follows: the size of the population is 500, and the maximum number of iterations is 500, It is possible to obtain the quantities of materials from the supply point to the distribution centre and from the distribution centre to the demand point in each cycle. Through the three algorithms, ISSA, SSA and GWO, all of them can get the material scheduling scheme of six cycles. Among them, the scheduling scheme obtained by solving ISSA algorithm is shown in Table 8.

Table 8 Scheduling schemes solved by ISSA algorithm.

Cyclicality	Distribution centres	Type of transport	Type of material	Demand point					
				n_1	n_2	n_3	n_4	n_5	n_6
First cycle	m_1	w_1	k_1	0	0	0	0	0	0
			k_2	0	0	0	0	0	0
		w_2	k_1	0	6257	6844	6899	0	0
			k_2	4812	5935	5272	0	3952	3549
	m_2	w_1	k_1	10997	3635	0	0	4945	0
			k_2	7162	0	0	4615	0	0
		w_2	k_1	0	0	1942	0	0	0

			k_2	0	0	0	0	0	0
Second cycle	m_1	w_1	k_1	0	0	0	0	0	0
			k_2	0	0	0	4577	0	3225
		w_2	k_1	0	0	0	0	0	0
			k_2	0	5887	0	0	0	0
	m_2	w_1	k_1	0	0	0	0	0	0
			k_2	6559	0	0	0	3903	0
		w_2	k_1	0	0	0	0	0	0
			k_2	0	0	5207	0	0	0
Third cycle	m_1	w_1	k_1	0	0	0	0	0	0
			k_2	6416	5711	0	0	3725	1330
		w_2	k_1	0	0	0	0	0	0
			k_2	0	0	4938	0	0	0
	m_2	w_1	k_1	0	0	0	0	0	0
			k_2	0	0	0	4447	0	0
		w_2	k_1	0	0	0	0	0	0
			k_2	0	0	0	0	0	0
Fourth cycle	m_1	w_1	k_1	0	0	0	0	0	0
			k_2	5983	5190	0	0	1187	0
		w_2	k_1	0	0	0	0	0	0
			k_2	0	0	4234	0	0	0
	m_2	w_1	k_1	0	0	0	0	0	0
			k_2	0	0	0	4086	0	0
		w_2	k_1	0	0	0	0	0	0
			k_2	0	0	0	0	0	851
Fifth cycle	m_1	w_1	k_1	1360	7245	0	0	0	0
			k_2	0	0	0	0	0	0
		w_2	k_1	0	0	2197	0	0	0
			k_2	0	0	0	0	0	0
	m_2	w_1	k_1	0	0	0	0	0	0
			k_2	5162	4347	0	3487	2722	0
		w_2	k_1	0	0	0	0	0	0
			k_2	0	0	3458	0	0	2054
Sixth cycle	m_1	w_1	k_1	0	0	0	0	0	0
			k_2	0	0	0	0	0	0
		w_2	k_1	0	0	0	0	0	0
			k_2	0	0	0	0	0	0
	m_2	w_1	k_1	0	6140	5053	0	0	0
			k_2	0	0	0	0	0	0

		w_2	k_1	0	0	0	4955	3961	1011
			k_2	1062	0	0	0	0	0

In order to verify the superiority of ISSA algorithm in solving the model, ISSA algorithm is compared with SSA algorithm and GWO algorithm, and the algorithm iteration comparison graph is shown in Figure 4, from which it can be seen that the ISSA algorithm can be solved to get a lower fitness value than the other two algorithms, indicating that ISSA algorithm possesses a higher solving accuracy and a better algorithmic performance in solving the multi-objective model constructed in this paper. On the other hand, SSA algorithm and GWO algorithm have converged after 200 iterations, while ISSA algorithm is still searching for the optimal solution after 200 iterations, which possesses a stronger ability of jumping out of the local optimum compared with the other two algorithms. In conclusion, the improved sparrow algorithm designed in this paper has good convergence accuracy and optimisation ability, and can effectively solve the multi-objective material scheduling problem.

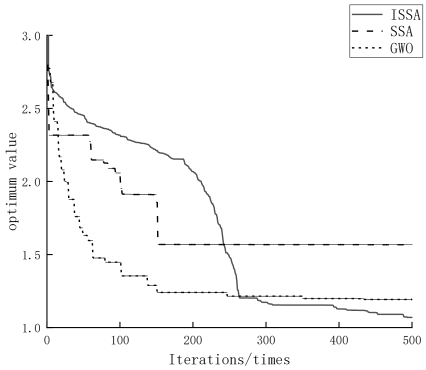


Figure 4 Comparison of algorithm iterations

6. Conclusion

After the occurrence of a major public health event, the efficiency and rationality of material dispatching is crucial. In order to solve the problem of multi-cycle and multi-modal material dispatching, a mathematical model with multiple supply points, multiple distribution centres and multiple demand points is constructed with timeliness, double fairness and economy as the objectives, aiming to achieve multi-cycle, multi-resource and multi-modal material dispatching. This model optimises the overall scheduling process by comprehensively considering the flow of materials at different stages and under different modes of transport. Aiming at the limitations of the standard sparrow algorithm in solving complex problems, we designed and applied an improved sparrow algorithm to solve the model. The improved sparrow algorithm makes various improvements in the search mechanism, convergence speed and global optimisation capability. Simulation results show that the improved sparrow algorithm designed in this paper can effectively solve the multi-period, multi-resource and multi-modal transport material scheduling model, and compared with the standard sparrow algorithm and the standard grey wolf algorithm, the improved sparrow algorithm has a superior solution effect, which can obtain a more reasonable and effective material scheduling scheme, and ensure that the materials can quickly and accurately arrive at the various points of demand in emergency situations.

The model constructed in this paper mainly considers the material distribution problem without considering the capacity constraints and distribution priority problems in the distribution process, the capacity constraints may lead to the inability to achieve the optimal scheduling in the case of limited resources, while the different urgency of the material demand needs to be prioritised in the scheduling process. Further research is needed on the models and algorithms that consider capacity constraints and material demand urgency.

Acknowledgements

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