Transactions on Computer Science and Intelligent Systems Research
ISSN: 2960-1800, eISSN: 2960-2238 | Volume 5
AIDML 2024

Particle swarm optimization for the Capacitated Helicopter Routing Problem

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Abstract. To improve the ability to prevent potential natural disasters, countries around the world are actively formulating emergency plans to protect people's lives and property. In this study, Sichuan Province was used as a case study to explore the allocation of medical supplies in a single distribution center using data from 21 cities and a storage base of medical supplies in Sichuan province. By constructing integer mixed nonlinear programming models-Planar helicopter Problem (HRP) and capacity-constrained Helicopter Routing Problem (CHRP), and using Particle Swarm Optimization (PSO) algorithm to solve the model, effective scheduling results and solutions are successfully obtained. It is found that the restriction of flight distance has a significant impact on the helicopter scheduling strategy, which in turn affects the consumption of human and material resources. The results of this study are valuable for practical applications.

Keywords: PSO; CHRP; Distribution of materials; Optimization model.

1. Introduction

Natural disasters have always been a major threat to human survival. In 2002, severe acute respiratory syndrome (SARS) occurred in Guangdong, China, and spread to Southeast Asia and even the world, causing damage to immune cells and lung epithelium of infected people, threatening health [1]. The COVID-19 pandemic, which started in 2019, has infected more than 250 million people worldwide so far, causing depression and anxiety to affect people's lives [2]. Sichuan Province of China is prone to natural disasters such as earthquakes and debris flows. To provide timely relief response to possible natural disasters in the future, this paper takes 21 cities in Sichuan Province of China as the research object to simulate the establishment of a medical material storage base covering hospitals in all regions of the province. Through simulation, the corresponding scheme of transporting the medical items in the base to the required hospital is given. After the construction of the base, the production of medical materials can be stored. When the city hospital needs materials, it can be deployed in time, which provides reference for the problem of material allocation.

To save manpower and material resources, we need to give a scheme to minimize the total flight mileage of the transport helicopter under some constraints. In this paper, we can reduce the Problem to Helicopter Routing Problem (HRP) and Capacitated Helicopter Routing Problem (CHRP), This Problem is like the Capacitated Vehicle Routing Problem (CVRP). CVRP and its derived problems have always been a focus of the scientific community. For example, Sean O 'Callaghan and Declan O'Conno et al. combined Geographic Information System (GIS) data to construct a dynamic decision support model for seasonal transportation of raw milk, which provides a model for milk collection for practitioners [3]. A robust periodic capacitated arc routing problem for urban waste collection considering the study of Erfan Babaee Tirkolaee et al drivers and crew’s working time [4]. Khanh Nguyen-Trong et al. combined GIG analysis to develop an optimization model for MSW transportation [5]. These models can provide reference value for some practical problems, and put forward effective reference schemes for actual production, urban pollutant transportation and other problems. Many people use new or improved optimization algorithms to solve such problems. For example, Eneko Osaba et al. Improved Bat Algorithm to solve a medical goods distribution problem with pharmacological waste collection [6]. Osman Gokalp and Aybars Ugur used A multi-start ILS-RVND algorithm with adaptive solution to solve the CVRP problem [7]. And its derivatives, such as the Dynamic Capacitated Vehicle Routing Problem (DCVRP), Multi-Compartment Vehicle Routing Problem (MCVRP), Vehicle Routing Problem with Time Windows (VRPTW) have also been studied by many people. Lukas Bach et al. compared the performance of GPU-based ALNS with state-of-the-art CPU implementations using the standard DCVRP benchmark, and the GPU-based ALNS yielded highly competitive performance [8]. Discussion and study of MCVRP by Islem Kaabachi et al [9]. J. Corstjens et al. applied multilevel statistical analysis to a large neighborhood search algorithm for VRPTW [10]. These studies all provide different and characteristic solutions to the derived problems of CVRP.

In this paper, we will establish a CHRP model like CVRP to solve the medical material distribution problem in Sichuan Province, and use PSO to calculate the satisfactory solution. PSO is a simulation optimization algorithm based on multiple intelligent agents, each intelligent agent through cooperation to better adapt to the environment, showing good interaction with the environment. It has self-organization, evolution and memory function, and can converge at a faster speed. The framework of this paper is as follows Figure 1.

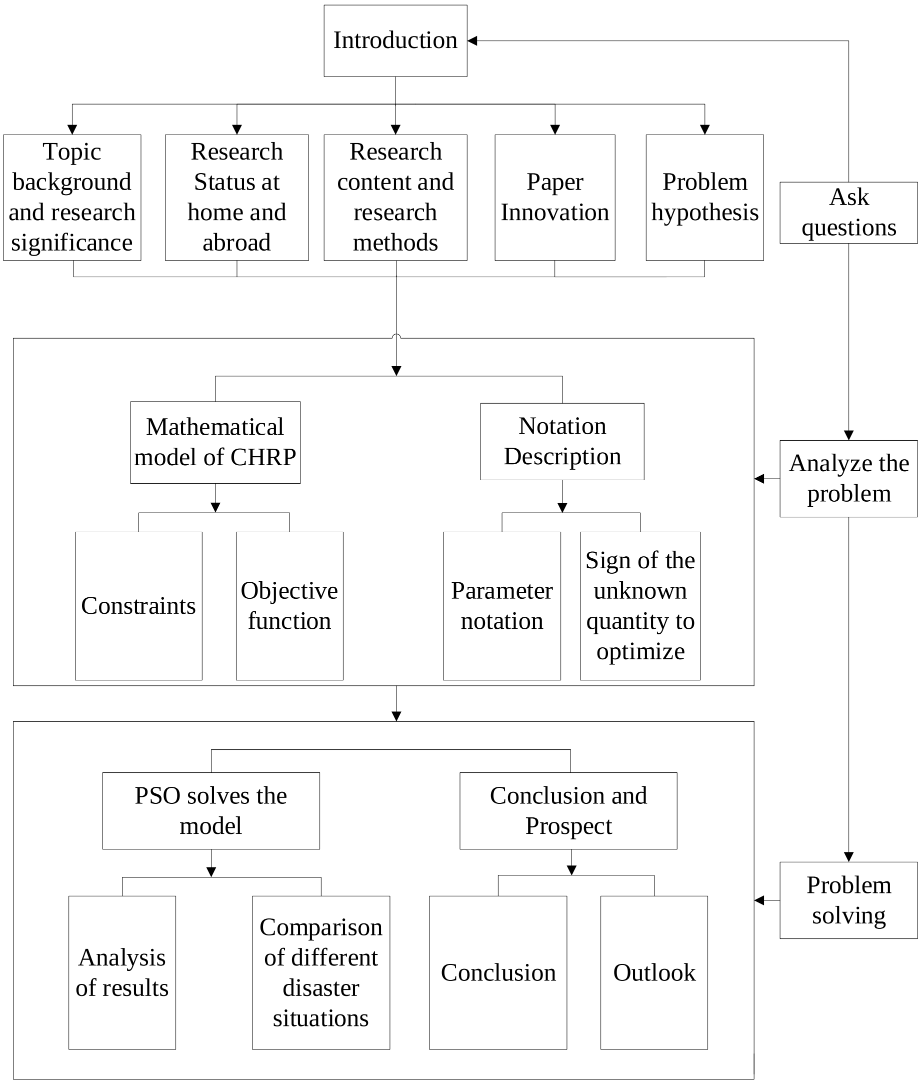

Figure 1. Flowchart of the article framework

2. Problem description and basic assumptions

2.1. Problem Description

To make the scheme of delivering materials efficient and low-cost, a CHRP with similar CVRP is established in this paper. The problem can be described as follows. To meet the medical supplies needs of hospitals in 21 cities, the corresponding transport helicopters were dispatched, and the appropriate paths were selected from the feasible flight paths, so that the transport helicopters could pass through each city hospital in an orderly manner. Under certain constraints (such as the demand for medical supplies, the supply of medical supplies, the capacity limit of transport helicopters, etc.), the material distribution to all urban hospitals is realized and the set goal (the shortest total flight distance) is achieved.

2.2. Basic assumptions of the problem

Considering the actual situation of the transportation process, the following basic assumptions are made for the distribution of medical materials:

(1) The material storage base is connected to the hospitals in each city.

(2) All material distribution must be completed within one cycle.

(3) The transport vehicle is Mi-26 transport helicopter with a maximum range of 2000 km, a maximum load of 12000 kg, and a flight speed of 255 km/h. The base has several 10.

3. Mathematical model

The medical supplies storage base needs to provide medical supplies distribution services to 21 urban hospitals in Sichuan Province. Each transport helicopter departs from the storage base, arrives at a series of urban hospitals on the way, and finally returns to the storage base. This subsection builds a general model around this problem.

3.1. Description of model notation

The model parameter symbols are given as follows Table 1. Parameter notation:

Table 1. Parameter notation

Symbol	Meaning	Unit
V	The set of all node indices, $V=\{0,1,...,21\}$	\
i, j	Node index, $\forall i, j \in V$	\
N	Transport helicopters set up, $N=\{1,2,...,10\}$	\
n	The NTH transport helicopter, $\forall n \in N$	\
D_{ij}	The geographical shortest distance between urban hospitals, $\forall i, j \in V$	*km*
$d_{\max}$	Maximum flight range of each transport helicopter	*km*
$w_{\max}$	Maximum payload of each transport helicopter	*kg*
Q_j	The number of supplies required by city hospital j	*kg*
$R(t)$	Loss rate function	%
r_n	Material loss rate of transport helicopter n, $\forall n \in N$	%
t_n	The flight time of transport helicopter n, $\forall n \in N$	*min*
a	Loss rate threshold	%
m_j^n	City hospital j receives the number of supplies from transport helicopter n, $\forall j \in \{1,2,...,21\}, \forall n \in N$	*kg*
Decision variable	\	\
x_{ij}^n	Decide whether the transport helicopter will fly from node to node, $j, \forall i, j \in V, \forall n \in N$	\

3.2. Objective function

The objective of this paper is to minimize the total flight distance of the transport helicopter, and the objective function is as follows:

$$Min \quad f = \sum_{n \in N} \sum_{i \in V} \sum_{j \in V} D_{ij} \cdot x_{ij}^{n} \tag{1}$$

3.3. Constrains

(1) City Hospital replenishment constraint: Must be resupplied and only once:

$$\sum_{n \in N} \sum_{j \in V} x_{ij}^{k} = 1 \tag{2}$$

(2) Constraint: The flight path of each transport helicopter must begin at the material storage base and eventually return to the base:

$$\sum_{j \in V} x_{0j}^{k} = 1, \sum_{i \in V} x_{i0}^{n} = 1 \tag{3}$$

(3) Flow constraint: The number of transport helicopters in and out of the city is equal:

$$\sum_{i \in V} x_{ih}^{n} = \sum_{j \in V} x_{hi}^{n} \tag{4}$$

(4) Loading capacity constraint of transport helicopter:

$$\sum_{i \in V} \sum_{j \in V} m_{j}^{n} \cdot x_{ij}^{n} \leq w_{\max} \cdot (1 - r_{n}) \tag{5}$$

(5) Range constraints of transport helicopter:

$$\sum_{i \in V} \sum_{j \in V} D_{ij} \cdot x_{ij}^{n} \leq d_{\max} \tag{6}$$

(6) Material demand constraints of urban hospitals:

$$\sum_{n \in N} m_{j}^{n} \geq Q_{j} \tag{7}$$

(7) Material loss rate constraint for each transport helicopter:

$$t_{n} = \sum_{i \in V} \sum_{j \in V} \frac{D_{ij} \cdot x_{ij}^{n}}{v} \tag{8}$$

$$R(t_n) = 4.51\times10^{-11}\cdot t_n^3 - 1.87\times10^{-11}\cdot t_n^2 + 1.59\times10^{-9}\cdot t_n - 3.35\times10^{-7} \le a \quad (9)$$

(8) Decision variable $0-1$ Constraints:

$$x_{ij}^n = \{0,1\} \quad (10)$$

3.4. Model solving method

Particle Swarm Optimization (PSO) is a modern heuristic algorithm, whose idea comes from the research on the foraging behavior of birds. Birds find the optimal foraging destination through collective information sharing, which has the advantages of fast convergence speed, few parameters and simple algorithm. The specific steps of the algorithm are as follows, and the overall process is as follows Figure 2.

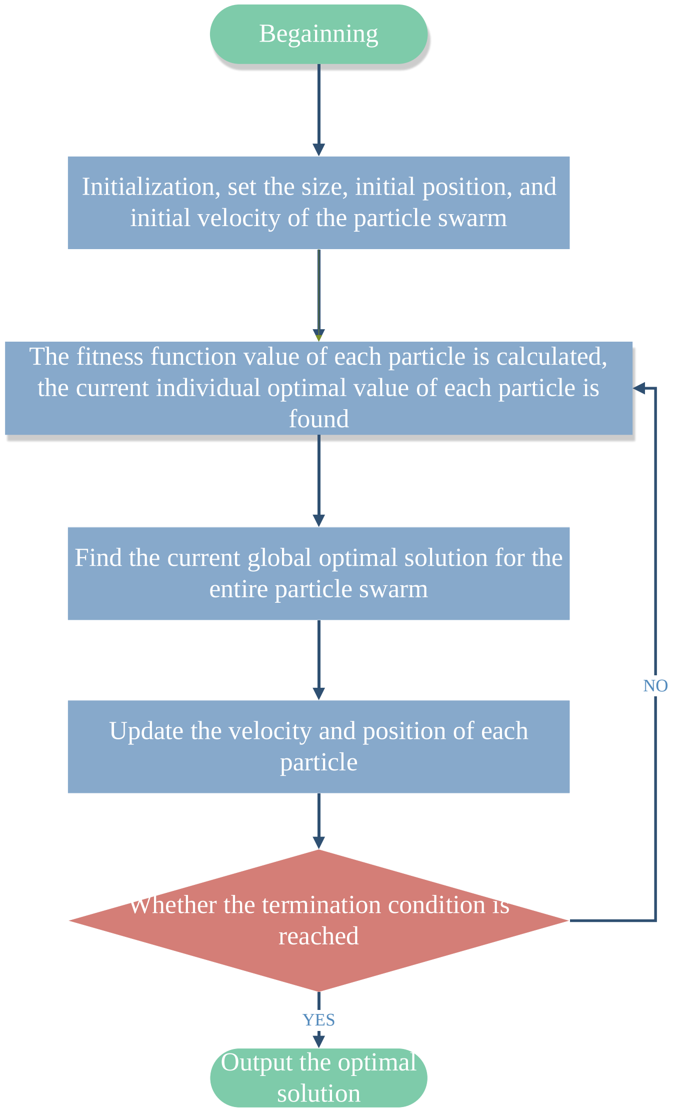

Figure 2. Flow chart of the PSO algorithm

Step1: The position and velocity of everyone in the population were initialized, the historical best pBest of the individual was set as the current position, and the best individual of the population was the current gBest.

Step2: The iteration was started. In the process of each iteration, the fitness function value of each individual particle was calculated.

Step3: For each individual particle, its fitness function value is compared with the fitness function value of the best position pBest it has experienced. If it is better, it is taken as the current best position pBest.

Step4: For each individual particle, its fitness function value was compared with the fitness function value of the global best position gBest experienced. If it was better, the index number of gBest was set again.

Step5: Update the velocity and position of individual particles.

Step6: If the end condition is not reached, go back to Step2, otherwise output gBest and end the algorithm.

In each iteration process, the individual particle updates its velocity and position through the individual extreme value and the group extreme value, and the update formula is as follows:

$$V_{plane\_new} = w \cdot V_{plane} + C_1 \cdot random(0,1) \cdot (P_{pBest} - X_{plane}) + C_2 \cdot random(0,1) \cdot (P_{gBest} - X_{plane}) \quad (11)$$

$$X_{plane} = X_{plane} + V_{plane\_new} \quad (12)$$

4. Results

4.1. Data Source Description

The longitude and latitude of each city in Sichuan province in this paper are from Sichuan Province Geographic Information Public Service Platform (tianditu.gov.cn), and the parameter data of Mi-26 are from Mi-26 helicopter Baidu Encyclopedia (baidu.com). The material demand of urban hospitals is assumed in this paper.

4.2. Rationality analysis

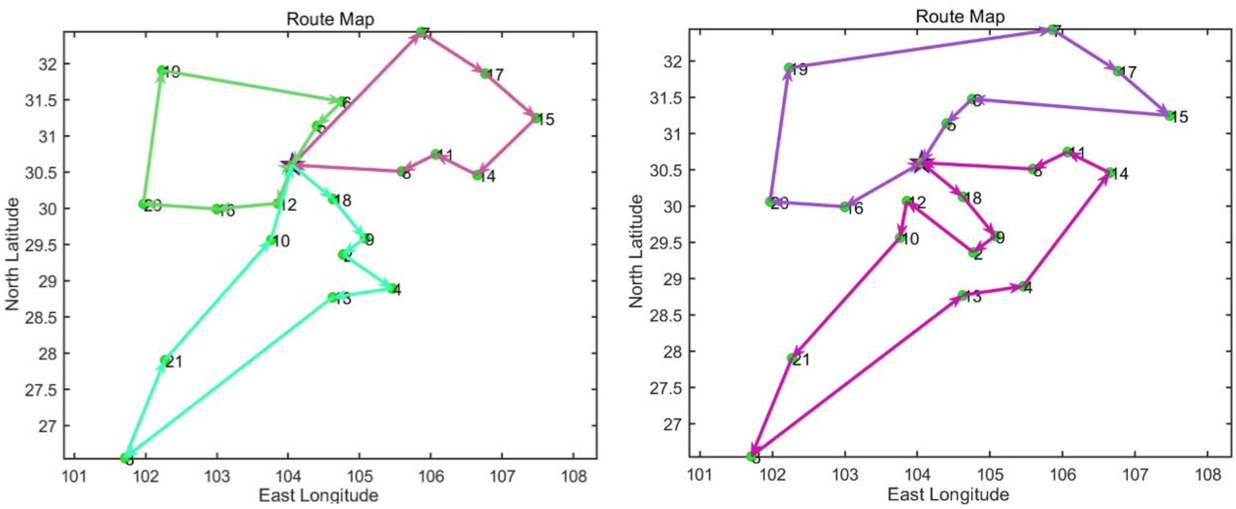

Figure 3. Solution result

In this paper, the model is solved by MATLAB software, and the integer mixed nonlinear programming problem can be effectively solved by using PSO, and the path diagram obtained is as follows Figure 3. The first figure shows the objective function obtained by scheme I (considering the maximum flight distance of the transport helicopter) and the result is $2814.4km$. A total of three transport helicopters will be dispatched to deliver medical supplies at the same time. The specific transport routes of the three transport helicopters are as follows Table 2. The second image shows the objective function obtained by scheme II (without considering the range constraint) and the result is $3008.2km$. A total of two transport helicopters will be dispatched to deliver medical supplies at the same time. The specific transport routes of the two transport helicopters are as follows Table 3.

Table 2. Scheme one

The NTH transport helicopter	Path	Distance of flight (km)
1	$0\rightarrow7\rightarrow17\rightarrow15\rightarrow14\rightarrow11\rightarrow8\rightarrow0$	820.3
2	$0\rightarrow18\rightarrow9\rightarrow2\rightarrow4\rightarrow13\rightarrow3\rightarrow21\rightarrow10\rightarrow12\rightarrow0$	1158.6
3	$0\rightarrow12\rightarrow16\rightarrow20\rightarrow19\rightarrow6\rightarrow5\rightarrow0$	835.5

Table 3. Scheme two

The NTH transport helicopter	Path	Distance of flight (km)
1	$0\rightarrow18\rightarrow9\rightarrow2\rightarrow12\rightarrow10\rightarrow21\rightarrow3\rightarrow13\rightarrow4\rightarrow14\rightarrow11\rightarrow8\rightarrow0$	1571.9
2	$0\rightarrow16\rightarrow20\rightarrow19\rightarrow7\rightarrow17\rightarrow15\rightarrow6\rightarrow5\rightarrow0$	1436.3

By comparing the two schemes, we can find that under the condition of scheme 2, there is no distance restriction on the transport helicopters, and the number of helicopters dispatched from the base is small but the total flight distance is large. However, under the condition of scheme 1, there is a distance limit for transport helicopters, and the number of helicopters dispatched from the base is large but the total flight distance is small. From the results of the two schemes, this model can deal with this kind of scheduling problem very well, and provides reference value for the real situation.

5. Conclusion

In this paper, a CPRP model like CVRP is developed by making reasonable assumptions on material transportation considering the dispatching of multiple transport helicopters to deliver medical supplies at one time. Considering the maximum flight distance constraint and the medical material loss rate constraint, the model simulates and optimizes the flight path of all transport helicopters to obtain the shortest total flight distance.

The innovation of this model is that the problem of material distribution by transport helicopter is compared to CVRP, and the loss of material is considered, and then the PSO is used to solve the model to obtain the result.

Vehicle routing planning is a typical NP-hard problem, and it is difficult to solve the medical material distribution problem of many target locations by using exact algorithms. Therefore, using improved intelligent optimization algorithms to solve such problems is a further research direction.

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