

MPPSO-Based Collaborative Optimization for Emergency Medical Supplies Loading and Scheduling

Hankun ZHANG, Jiayu SHEN, Jianna YANG, Robert OJSTERSEK*

Abstract: Public emergency occurs frequently, which has a serious impact on people's life safety and social stability. When public emergency occurs, the government needs to respond quickly to reduce casualties and property losses. Emergency medical supplies scheduling is the key work of government response, which is a scheduling problem. To solve the scheduling problem, firstly, we designed a collaborative system of loading and scheduling of emergency medical supplies. Secondly, considering the waiting time and the affected level of the affected point, and the conflict time of loading and unloading, a loading and scheduling collaborative optimization model of emergency medical supplies is constructed, the objective of which is the minimum maximum weighted time of all affected points. Thirdly, based on the Multi-phase Particle Swarm Optimization (MPPSO), an improved Multi-phase Particle Swarm Optimization (IMPPSO) is designed to improve the ability to solve the constructed collaborative optimization model. Finally, by taking the rainstorm event in Fangshan District on July 31, 2023 as an example, the proposed method has obtained an efficient scheduling solution in a reasonable time. The average fitness obtained by IMPPSO is 15.58% and 42.95% better than that of MPPSO and Particle Swarm Optimization (PSO), respectively. It is proved that the proposed method has good feasibility in practical application, which provides emergency medical supplies scheduling decision support for emergency management departments in public emergency.

Keywords: emergency medical supplies; loading and scheduling collaborative; multi-phase particle swarm optimization; public emergency

1 INTRODUCTION

The public emergency generally refers to sudden public emergency involving public safety [1]. Compared with general supplies, the demand for emergency medical supplies is more urgent and its volume is smaller. Its uniqueness requires rapid and accurate allocation of rescue resources to ensure timely and effective relief to the affected people. In order to ensure the timely supply of emergency medical supplies, it is necessary to collaboratively optimize the loading and scheduling of emergency medical supplies. Manual scheduling consumes a lot of manpower and time, which also lacks scientific planning and calculation. The collaborative optimization problem of emergency medical supplies requires an efficient method. It requires efficient method to enhance China's ability to respond to public emergency.

The scheduling of emergency medical supplies is a key issue in the research. Rescue resource scheduling models have been proposed to achieve emergency resource scheduling. Wu et al. [2] considered the demand changes of different types of medical supplies in different periods and the impact of traffic control on transportation modes, and established an optimization model for emergency medical supplies in rescue points. Li et al. [3] considered the location of medical points, the distribution of infected persons and the distribution of medical supplies in multi-stage planning. Li et al. [4] established a multi-objective mobile emergency material allocation model by taking mobile emergency cost and mobile emergency time as two objective functions. Hu et al. [5] proposed a method including two recursive mechanisms of time-varying prediction of medical resources and emergency medical resource allocation, and constructed a bi-objective optimization model to determine the optimal medical resource allocation scheme. Yuan et al. [6] constructed a tripartite evolutionary game model to study the allocation of medical supplies in the rescue environment of public health events under incomplete information. Wang et al. [7] established an optimal allocation model of multi-cycle

emergency resources considering the heterogeneity of affected areas, aiming to make the allocation of resources more fair, efficient and economical. Moura et al. [8] studied the mathematical method of integrating the three-dimensional packing problem with simultaneous delivery and pickup with the vehicle routing problem. The scheduling of emergency medical supplies has the characteristics of high timeliness requirements and complex and changeable scheduling environment. Scholars have established a variety of mathematical models to solve the scheduling problem of emergency medical supplies, to realize the rational scheduling of emergency medical supplies. Zhao et al. [9] constructed an urban emergency medical equipment distribution model considering demand urgency, distribution time window and vehicle load limit. An et al. [10] established a bi-objective vehicle routing problem considering demand urgency and response cost minimization, which was solved by Particle Swarm Optimization. Peng et al. [11] studied the location-routing problem of maritime emergency material distribution based on two-level planning.

The scheduling problem of emergency medical supplies is difficult to integrate resources, dynamic and needs to achieve multi-objective optimization. The methods of solving the scheduling problem are proposed. Based on Markov decision process, Wang et al. [12] studied the scheduling strategy of emergency medical supplies for public health emergencies such as COVID-19. Liu et al. [13] proposed a scheduling method for medical supplies in major public health emergencies to develop a fast and accurate medical supplies supply plan. Xia et al. [14] proposed a large-scale emergency medical supplies scheduling algorithm to solve the problem of low turnover efficiency of medical supplies and unbalanced scheduling of supply and demand points in public health emergencies. Marković et al. [15] associated resource planning with vehicle routing problem, encompassing the process of distribution to customers, seeking to minimize the number of vehicles, delivery time, and overall distance travelled. Chen [16] comprehensively considered the

capacity constraints of distribution centers, time constraints, material needs of disaster relief points and different means of transportation, constructed a dual-objective path planning with multiple distribution centers and multiple disaster relief points. Zhang et al. [17] studied the vehicle routing optimization of emergency material distribution considering vehicle maintenance and driver's continuous working ability. Zhao et al. [18] proposed a strategy of distributing supplies from peripheral areas to the epicentre and gave a supply-side selection model considering the epidemic influence and supplies condition in the candidate supply-side areas. Ruan et al. [19] used balanced fuzzy clustering to optimize the multimodal transport of emergency medical supplies, and provided operational support for the 'helicopters and vehicles' intermodal transportation of medical supplies in response to large-scale disasters

The existing research lacks full consideration of the characteristics of emergency medical supplies. The optimization objective of scheduling lacks consideration of fairness. Moreover, the loading and scheduling optimization are not considered collaboratively. Therefore, this paper proposed a method to improve the loading and scheduling efficiency of emergency medical supplies.

Considering the waiting time and the affected level of the affected point, and the conflict time of loading and unloading, a collaborative optimization model with the objective of minimizing the maximum weighted time of emergency medical supplies for all affected points is constructed. Based on the Multi-phase Particle Swarm Optimization, an improved Multi-phase Particle Swarm Optimization is proposed to obtain the optimal solution of collaborative optimization model quickly and accurately.

The remainder of this paper is organized as follows. The section 2 proposes the collaborative system of loading and scheduling of emergency medical supplies in public emergency. The section 3 constructs a loading and scheduling collaborative optimization model for emergency medical supplies in public emergency. The section 4 designs a swarm intelligence algorithm. The example experiment is carried in the section 5, followed by the conclusions in Section 6.

2 METHODOLOGY

In public emergency, distributing emergency medical supplies is vital. It has a small batch of significant characteristics and thus requires separate distribution. Therefore, the collaborative system of loading and scheduling of emergency medical supplies is constructed. Fig. 1 shows the collaborative system of loading and scheduling of emergency medical supplies. In the collaborative system of emergency medical supplies, the affected points report affected information and demand information. After the emergency medical management department issued the request, relevant scheduling centers responded accordingly. The emergency vehicle scheduling center reported the status and availability of vehicles. Meanwhile, the emergency medical supplies scheduling center provided the current inventory information of supplies. By inputting parameters to the proposed method, the emergency medical supplies loading and scheduling solution is generated for the emergency medical

management department. At the same time, the scheduling information will also be shared to the emergency medical supplies scheduling center, emergency vehicle scheduling center and affected points and other departments. In the collaborative system of emergency medical supplies, the collaborative scheduling method is the core, which includes the collaborative scheduling model and its solution algorithm.

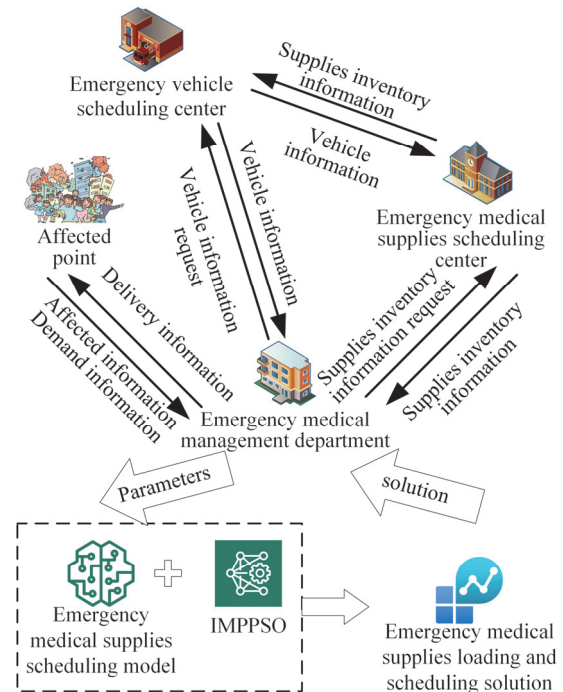


Figure 1 The collaborative system of emergency medical supplies

3 METAHEURISTIC MODEL

3.1 Problem

The collaborative optimization of emergency medical supplies loading and scheduling is a complex optimization problem.

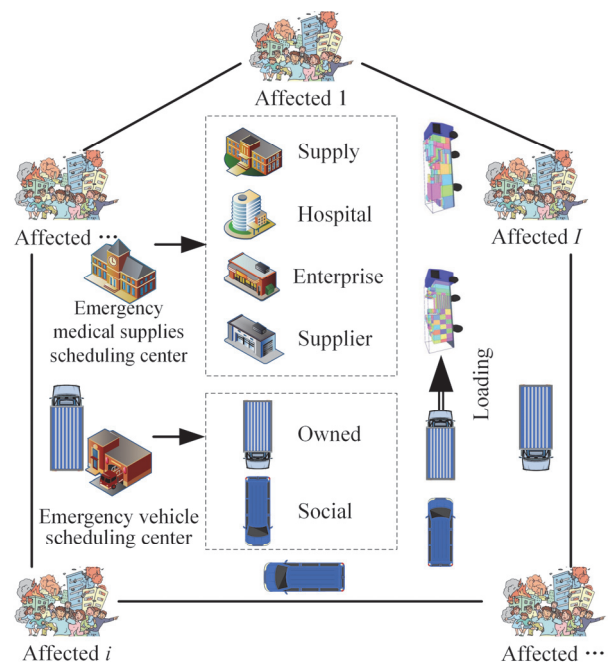


Figure 2 The collaborative optimization problem of emergency medical supplies

It is necessary to consider the affected level of each point and its specific needs for emergency medical supplies, including type and quantity. And it is also necessary to consider the inventory quantity of emergency medical supplies and the capacity of emergency transport vehicles. The numbers of affected points and emergency medical supplies are denoted as I and J , the numbers of owned and social vehicles are denoted as M_1 and M_2 , the numbers of the supplies, hospitals, enterprises, and suppliers are denoted as K_1, K_2, K_3 , and K_4 , M and K are set to $M = M_1 + M_2$ and $K = K_1 + K_2 + K_3 + K_4$ respectively. The affected points are set to $A = \{1, \dots, i, \dots, I\}$. The emergency medical supplies are set to $B = \{1, \dots, j, \dots, J\}$. The emergency transport vehicles are set to $O = \{1, \dots, m, \dots, M_1, M_1 + 1, \dots, M_1 + M_2\}$. The supply points are set to $P = \{1, \dots, k, K_1, K_1 + 1, \dots, K_1 + K_2, \dots, K_1 + K_2 + 1, \dots, K_1 + K_2 + K_3, K_1 + K_2 + K_3 + 1, \dots, K_1 + K_2 + K_3 + K_4\}$. The loading and scheduling collaborative optimization problem of emergency medical supplies is shown in Fig. 2.

3.2 Assumption

(1) The type, quantity, length, width, height, and quality of emergency medical supplies required in each affected are known.

(2) The emergency transport vehicle information that can be used by the emergency vehicle scheduling center is known, such as the capacity and volume of the vehicle.

(3) The carriage of emergency transport vehicles and emergency medical supplies is cuboid. And emergency medical supplies are inelastic and incompressible.

(4) The medical emergency supplies in the carriage are not crossed, not overlapped, not nested, and not inclusive.

(5) When the unloading operation is carried out at the current affected point, the number of affected points that need to deal with the unloaded non-target supplies before it is defined as the loading and unloading conflict order. The additional loading and unloading time caused by the loading and unloading conflict order will increase exponentially with the loading and unloading conflict order.

(6) The loading and unloading time is mainly related to the weight of supplies, and has nothing to do with the vehicles or supply points. Therefore, the loading operation time at the supply point and the unloading operation time at the affected point are not considered.

(7) The distance between the two points is calculated according to their latitude and longitude.

3.3 Model

In order to realize the efficient scheduling of emergency medical supplies, a collaborative optimization model of emergency medical supplies loading and scheduling is constructed. The parameters or variables are as follows:

D_{ij} : The demand quantity of emergency medical supplies j of affected point i .

V_{ij} : The demand volume of emergency medical supplies j of affected point i .

S_{kj} : The supply quantity capacity of emergency medical supplies j in the supply point k .

C_m : The weight capacity of emergency transport vehicle m .

F_m : The volume capacity of emergency transport vehicle m .

w_i : The time that the affected point i has been waiting for scheduling.

t_i : The time when the vehicle reaches the affected point i .

l_i : The affected level of the affected point i .

n_i : The loading and unloading conflict order of affected point i .

Δt : The penalty coefficient.

T_i : The weighted time of the affected point i .

x_{ijkm} : The binary variable, equal to 1 if the medical emergency supplies j of the affected point i are supplied by the supply point k and transported by the emergency transport vehicle m , and 0 otherwise.

The key objective of emergency medical supplies scheduling is the supply time. Supply time is also affected by loading and unloading conflict. In order to ensure that the scheduling of emergency medical supplies is fairer, the waiting time and affected level of the affected point are also considered. They are considered in an exponential form to highlight their impact. The collaborative optimization model is as follows:

$$f = \min[\max T_i] \tag{1}$$

$$T_i = \begin{cases} e^{l_i} \cdot (w_i + t_i), & n_i = 0 \\ e^{l_i} \cdot (w_i + t_i) + e^{n_i} \cdot \Delta t, & n_i \geq 1 \end{cases} \tag{2}$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K x_{ijkm} D_{ij} \leq C_m, \forall m \in M \tag{3}$$

$$\sum_{i=1}^I \sum_{j=1}^J \sum_{k=1}^K x_{ijkm} V_{ij} \leq F_m, \forall m \in M \tag{4}$$

$$\sum_{i=1}^I \sum_{m=1}^M x_{ijkm} D_{ij} = S_{kj}, \forall k \in K, \forall j \in J \tag{5}$$

$$\sum_{k=1}^K x_{ijkm} = 1, \forall i \in I \tag{6}$$

$$\sum_{m=1}^M x_{ijkm} = 1, \forall i \in I \tag{7}$$

$$\sum_{m=1}^M \sum_{k=1}^K \sum_{i=1}^I \sum_{j=1}^J x_{mkij} = 1 \tag{8}$$

Eq. (1) is the optimization objective to minimize the maximum weighted time of emergency medical supplies for all affected points. Eq. (2) is the weighted time of the affected point i . e^{w_i/l_i} represents the influence of the waiting time and the affected level of the affected point i . e^{n_i} represents the influence of the conflict order of the loading and unloading of the affected point i . Eq. (3) and Eq. (4) are the constraint of the vehicle weight and volume capacity. The weight and volume of the loaded emergency medical supplies cannot exceed the vehicle weight and volume capacity, respectively. Eq. (5) explains the supply quantity capacity constraint of the supply point. Eq. (6) and

Eq. (7) represent the only constraint, respectively indicate that the emergency medical supplies of each affected point can only be supplied by a supply point and transported by an emergency transport vehicle. Eq. (8) indicates that each kind of emergency medical supplies at each affected point can only be supplied by a supply point and transported by an emergency transport vehicle.

4 ALGORITHM DESIGN

In order to solve complex combinatorial optimization problem, such as high dimension and strong constraints, an improved Multi-phase Particle Swarm Optimization (IMPPSO) is proposed, which is based on Multi-phase Particle Swarm Optimization (MPPSO) proposed by Al-Kazemi [20]. In the IMPPSO, improvement strategies are adopted, including selecting sub-dimensions randomly, introducing the contraction expansion coefficient and mutation operation, generating random numbers by the Tent Chaotic Map and handling constraints. In the IMPPSO, firstly, the parameters, population and global optimal position are initialized. In the population iterative evolution, particle iteration is followed by calculating the parameters of the current iteration. In the particle update, the parameters of the current particle are calculated first, followed by the sub-dimension update. After the particles are updated, the mutation operation is introduced. Finally, the global best position is updated. The pseudocode of IMPPSO is shown in Algorithm 1[20].

Algorithm 1 The pseudocode of IMPPSO

```

Step 0: Initialize parameter. The size of the swarm  $N_s$ , the
dimension of the problem  $N_d$ , the number of phases  $ph$ , the
phase change frequency  $pcf$ , the number of groups within each
phase  $g$ , the subdimension length  $sllu = [1, \min(10, N_d)]$ , the
velocity change variable  $VC$ , the range of contraction expansion
coefficient starting value of  $beta\_max$  is used to initially
accommodate a more global search and is dynamically reduced
to  $beta\_min$ , the mutation parameter  $a$ , the maximum number of
iterations  $max\_ite$ . Initialize the iteration value  $ite = 0$ .
Step 1: Initialize population. Initialize the position of the  $i$ -th
particle. Evaluate the fitness of the  $i$ -th particle.
Step 2: Initialize global best position.
Step 3: Population iterative evolution.
For  $ite = 1: max\_ite$ 
  Step 3.1: Calculate the parameters of the current iteration.
  Step 3.2: Update particle.
  For  $I = 1: N_s$ 
    Step 3.2.1: Calculate the current individual parameters.
    Step 3.2.2: Update sub-dimension.
    while  $\sim$  is empty( $dim\_set$ )
      Step 3.2.2.1: Get the current updated sub-dimensions.
      Step 3.2.2.2: Cache the position of the current particle.
      Step 3.2.2.3: Set the coefficient's value in each group
      within each phase.
      Step 3.2.2.4: Update the velocity of the current particle.
      Step 3.2.2.5: Update the temporary position.
      Step 3.2.2.6: Handling the constraints.
      Step 3.2.2.7: Evaluate the fitness of the temporary
      position.
      Step 3.2.2.8: Update the position of the current particle
      if the temporary position gets better fitness.
      Step 3.2.2.9: Delete the updated dimension.
    end
  end
  Step 3.3: Implement the mutation operator.

```

```

Step 3.3.1: Choose to update the individual.
Step 3.3.2: Select the update dimension.
Step 3.3.3: Calculate the range of variation.
Step 3.3.4: Using  $N(0, 1)$ , which is a Gaussian scheduling
with 0 and 1, to generate a new position.
Step 3.3.5: Cache the position of the current particle.
Step 3.3.6: Handling the constraints.
Step 3.3.7: Evaluate the fitness of the temporary position.
Step 3.3.8: Update the position of the mutation particle if
the temporary position gets better fitness.
Step 3.4: Update global best position.
end

```

4.1 Selecting Sub-dimensions Randomly

In the process of particle update of the IMPPSO, the sub-dimensions are randomly selected [21]. In the process of particle update, the length of the random update sub-dimension is first determined, followed by the sub-dimension update. In the process of sub-dimension update, the update of sub-dimension is iterated until all sub-dimensions are updated. In the iterative process of updating sub-dimensions, the sub-dimensions length determined previously are randomly selected to update each time from the sub-dimensions that have not been updated. The updated sub-dimensions will be deleted from the set of unupdated sub-dimensions. If the length of the set of unupdated sub-dimensions is less than the previously determined length, all remaining unupdated sub-dimensions are updated.

4.2 Introducing the Contraction Expansion Coefficient

Inspired by literature [22], the contraction expansion coefficient is introduced in the IMPPSO. The contraction expansion coefficient inherits the idea of dynamic adjustment of the inertia weight of the Particle Swarm Optimization (PSO). By dynamically scaling the velocity update range of particles, the convergence of the IMPPSO is enhanced, and its adaptability for complex problem is improved.

4.3 Introducing the Mutation Operation

Inspired by literature [23], the mutation operation is introduced in the IMPPSO. Different from literature [23], the mutation probability increases with the increase of the number of iterations, which increases the mutation probability in the later stage of iteration. It enhances the global exploration ability and improves the robustness and adaptability of the IMPPSO to solve high-dimensional and strongly constrained practical problem. In the mutation operation, the particles are first randomly selected for updating, followed by a sub-dimension of the randomly selected particles for updating.

4.4 Generating Random Numbers by the Tent Chaotic Map

In the IMPPSO, all random numbers are generated by the Tent Chaotic Map, which is inspired by literature [22]. The Tent chaotic map has the characteristics of ergodicity, uniform scheduling, and initial value sensitivity. This strategy is applied to the IMPPSO to make the particles

explore more evenly in the search space and avoid premature aggregation to the sub-optimal solution area. It can improve the global search ability of IMPPSO, which optimizes the convergence efficiency and enhances the adaptability to complex problem.

4.5 Handling Constraints

Two types of constraints are handled, which are boundary constraints and capacity constraints.

First, the boundary constraints are handled. When a dimension x_{ij} of a particle exceeds its boundary range, the IMPPSO handles the dimension by the following strategy: It has a 25% probability of being replaced by a randomly generated number, a 50% probability of being replaced by the dimension corresponding to the global best position, and a 25% probability of being replaced by the corresponding boundary value. When using the boundary value to replace, if it exceeds the upper boundary, the upper boundary is used, otherwise the lower boundary is used. It achieves an efficient balance between exploration and development in handling constraints, which improves the robustness and practicability of the IMPPSO.

Then, the capacity constraints are handled when calculating the fitness. The model incorporates both the weight and volume limitations of each vehicle. The total

weight and volume of emergency medical supplies loaded onto a vehicle must remain within its respective capacity bounds. Additionally, the supply quantity constraint at each supply point is addressed. For each type of emergency medical supply, the dispatched quantity from a supply point cannot exceed its available inventory. Violating any capacity constraint means that the current solution is not feasible.

5 NUMERICAL EXPERIMENT

5.1 Encoding Solution

The design of the encoding scheme plays a critical role in the application of swarm intelligence algorithms. It serves as the foundation for solving the collaborative optimization problem of emergency medical supplies loading and scheduling. An effective coding strategy ensures that solution representations are both feasible and computationally efficient. The example of coding solution is shown in Fig 3. In Fig. 3, the APN, SN, SPN, and $L \times W \times H$ represent the affected point number, supplies number, supply point number, and length \times width \times height, respectively.

Affected point information

No	Name	Abbr.	Location	Level	Waiting time (h)
1	Chengguan	A1	116,020408, 39,7118770	III	0,14
2	Xinzhen	A2	116,067560, 39,7400470	III	0,55
3	Xiangyang	A3	115,990514, 39,7234930	IV	0,18
4	Dongfeng	A4	115,967826, 39,7590250	IV	0,29
5	Yingfeng	A5	115,966588, 39,7318720	IV	0,43
6	Xingcheng	A6	116,070075, 39,7169010	IV	0,12

Demand information

No	APN	SN	Weight (t)	Volume (m ³)	No	APN	SN	Weight (t)	Volume (m ³)
1	1	1	0,1011	0,4850	7	4	1	0,1031	0,4950
2	1	2	0,0320	0,1602	8	4	2	0,1320	0,1802
3	2	1	0,0271	0,0459	9	5	1	0,0371	0,0659
4	2	2	0,0113	0,0180	10	5	2	0,0213	0,0380
5	3	1	0,0695	0,8334	11	6	1	0,0295	0,2334
6	3	2	0,0650	0,3249	12	6	2	0,0150	0,0249

Supply point information

No	Name	Abbr.	Type	Location
1	Liangxiang Hospital of Fangshan District	S1	Hospital	116,146981, 39,743042
2	Doudian Central Hospital of Fangshan District	S2	Supply	116,071540, 39,654030
3	Beijing Shuokang Medical Device Co., Ltd.	S3	Supplier	116,094966, 39,747560
4	Beijing Jiuhel Pharmaceutical Co., Ltd.	S4	Enterprise	116,089098, 39,654113

Supply Point Information

No	SPN	SN	Weight (t)	No	SPN	SN	Weight (t)
1	1	1	1,93	5	3	1	2,93
2	1	2	1,33	6	3	2	2,33
3	2	1	2,25	7	4	1	4,25
4	2	2	3,88	8	4	2	4,88

Vehicle informational

No	Name	Type	Load (t)	$L \times W \times H$ (m)	Speed (km/h)	Location	Available time (h)
1	Vehicle 1	Owned	5	$5,2 \times 2,1 \times 2,1$	59	116,137009, 39,728670	0,30
2	Vehicle 2	Social	6	$6,2 \times 2,3 \times 2,0$	58	116,151655, 39,750781	0,25

Supplies information

No	Name	Grade
1	Respiratory infection	II
2	Antipyretic analgesic	I

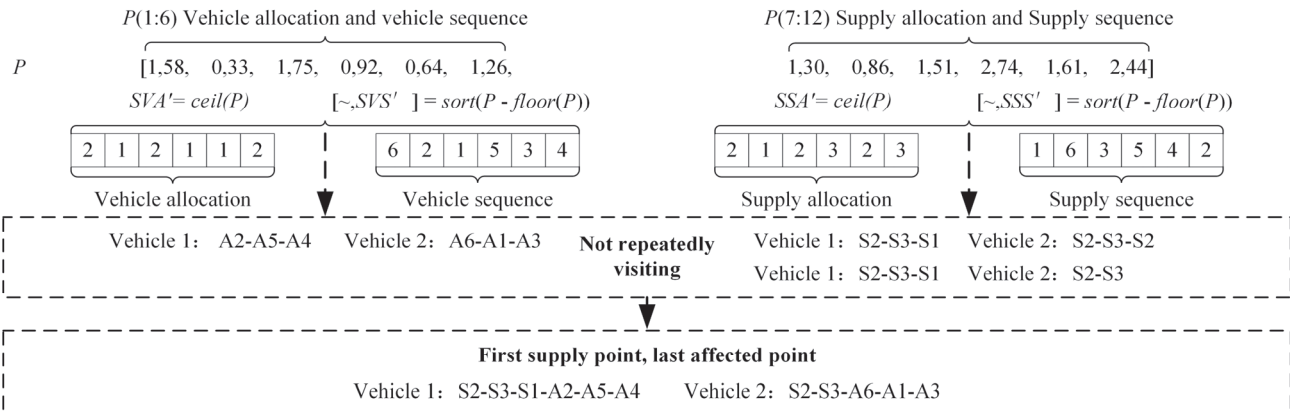


Figure 3 The example of coding solution

In the coding solution, the relative position indexing [24] is introduced. The first half of each particle dimension is used for emergency transport vehicle allocation and visiting sequencing of the affected point, while the latter half is used for supply point allocation of the affected point and visiting sequencing of the supply point. The upward rounding of each sub-dimension in the first half is used to allocate emergency transport vehicles, while the ascending sort of the decimal portion is used for visiting sequencing, which means that the smaller the decimal portion, the higher the visiting sequencing priority. Similarly, the upward rounding of each sub-dimension in the latter half is used to allocate supply points, while the ascending sort of the decimal portion is used for visiting sequencing, which means that the smaller the decimal portion, the higher the visiting sequencing priority. Meanwhile, the two strategies of not repeatedly visiting the supply point and first supply point last affected point are applied in the decoding process.

5.2 CASE STUDY

5.2.1 Case Description

Taking the rainstorm in Fangshan District on July 31, 2023 as an example, the supplies information, the affected

point information, the supplies demand, the supply point information, the supply information and the vehicle information are shown in Tab. 1 to Tab. 6. In Tab. 3, the AP-S represents the affected point number - supplies number. Fig. 4 shows the distribution of affected points, supply points and vehicles.

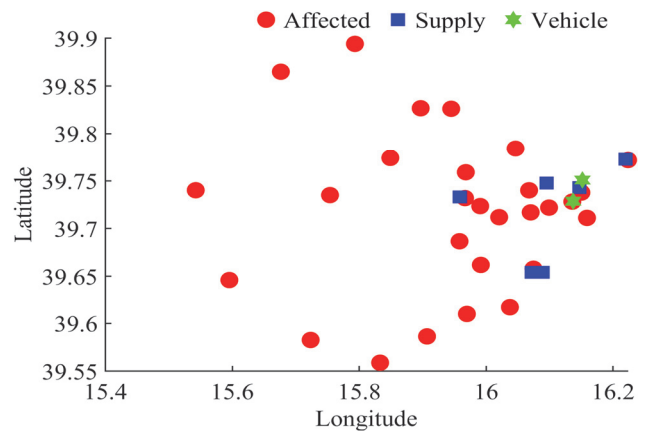


Figure 4 The distribution of affected points, supply points and vehicles

Table 1 The supplies information

No	Name	Grade	No	Name	Grade	No	Name	Grade
1	Respiratory infection	II	3	Diarrhea non-prescription drugs	II	5	Hydrogen peroxide disinfectants	III
2	Antipyretic analgesic	I	4	Alcohol disinfectants	I	6	Other	III

Table 2 The affected point information

No	Name	Position	Level	Waiting time / h	No	Name	Position	Level	Waiting time / h
1	Chengguan	116,020408, 39,711877	III	0,14	15	Changyang	116,223547, 39,771814	IV	0,26
2	Xinzhen	116,067560, 39,740047	III	0,55	16	Hebei	115,944796, 39,826192	II	0,35
3	Xiangyang	115,990514, 39,723493	IV	0,18	17	Changgou	115,906703, 39,586395	III	0,11
4	Dongfeng	115,967826, 39,759025	IV	0,29	18	Dashiwo	115,832755, 39,558883	III	0,62
5	Yingfeng	115,966588, 39,731872	IV	0,43	19	Zhangfang	115,723263, 39,582646	III	0,2
6	Xingcheng	116,070075, 39,716901	IV	0,12	20	Shidu	115,595141, 39,646009	II	0,43
7	Liangxiang	116,158891, 39,711137	IV	0,04	21	Qinglonghu	116,046202, 39,784183	III	0,12
8	Zhoukoudian	115,957947, 39,686672	II	0,5	22	Hancunhe	115,969544, 39,609838	III	0,59
9	Liulihe	116,037363, 39,616843	III	0,49	23	Xiayunling	115,753778, 39,735001	II	0,4
10	Gongchen	116,150024, 39,737663	IV	0,52	24	Nanjiao	115,848845, 39,774055	II	0,33
11	Xilu	116,135687, 39,728165	IV	0,02	25	Fozizhuang	115,896705, 39,826738	II	0,14
12	Yancun	116,099022, 39,721893	III	0,17	26	Daanshan	115,793079, 39,894174	II	0,44
13	Doudian	116,074436, 39,657897	III	0,08	27	Shijiyang	115,676332, 39,864998	II	0,66
14	Shilou	115,991528, 39,661887	III	0,28	28	Puwa	115,542150, 39,740112	II	0,33

Table 3 The supplies demand

No	AP-S	Weight / t	Volume / m ³	No	AP-S	Weight / t	Volume / m ³	No	AP-S	Weight / t	Volume / m ³	No	AP-S	Weight / t	Volume / m ³
1	1-1	0,1011	0,4850	43	8-1	0,0349	0,1675	85	15-1	0,2014	0,9667	127	22-1	0,0312	0,1498
2	1-2	0,3637	1,8186	44	8-2	0,1256	0,6279	86	15-2	0,7251	3,6255	128	22-2	0,1123	0,5616
3	1-3	0,2425	2,9100	45	8-3	0,0838	1,0050	87	15-3	0,4834	5,8008	129	22-3	0,0749	0,8982
4	1-4	0,1718	0,2910	46	8-4	0,0593	0,1005	88	15-4	0,3424	0,5800	130	22-4	0,0530	0,0899
5	1-5	0,0606	0,0970	47	8-5	0,0209	0,0335	89	15-5	0,1208	0,1933	131	22-5	0,0187	0,0300
6	1-6	0,1039	0,5196	48	8-6	0,0359	0,1794	90	15-6	0,2072	1,0359	132	22-6	0,0321	0,1605
7	2-1	0,0089	0,0427	49	9-1	0,0557	0,2671	91	16-1	0,0158	0,0756	133	23-1	0,0041	0,0194
8	2-2	0,0320	0,1602	50	9-2	0,2003	1,0017	92	16-2	0,0567	0,2835	134	23-2	0,0146	0,0732
9	2-3	0,0214	0,2562	51	9-3	0,1336	1,6026	93	16-3	0,0378	0,4536	135	23-3	0,0098	0,1170
10	2-4	0,0151	0,0256	52	9-4	0,0946	0,1603	94	16-4	0,0268	0,0454	136	23-4	0,0069	0,0117
11	2-5	0,0053	0,0085	53	9-5	0,0334	0,0534	95	16-5	0,0095	0,0151	137	23-5	0,0024	0,0039
12	2-6	0,0092	0,0459	54	9-6	0,0572	0,2862	96	16-6	0,0162	0,0810	138	23-6	0,0042	0,0210
13	3-1	0,0160	0,0766	55	10-1	0,1789	0,8585	97	17-1	0,0184	0,0881	139	24-1	0,0027	0,0127
14	3-2	0,0574	0,2871	56	10-2	0,6439	3,2193	98	17-2	0,0660	0,3300	140	24-2	0,0096	0,0480
15	3-3	0,0383	0,4596	57	10-3	0,4293	5,1510	99	17-3	0,0440	0,5280	141	24-3	0,0064	0,0768
16	3-4	0,0271	0,0459	58	10-4	0,3041	0,5151	100	17-4	0,0312	0,0528	142	24-4	0,0045	0,0076
17	3-5	0,0096	0,0153	59	10-5	0,1073	0,1717	101	17-5	0,0110	0,0176	143	24-5	0,0016	0,0025

Table 3 The supplies demand - continuation

No	AP-S	Weight / t	Volume / m ³	No	AP-S	Weight / t	Volume / m ³	No	AP-S	Weight / t	Volume / m ³	No	AP-S	Weight / t	Volume / m ³
18	3-6	0,0164	0,0819	60	10-6	0,1840	0,9198	102	17-6	0,0188	0,0942	144	24-6	0,0028	0,0138
19	4-1	0,0188	0,0902	61	11-1	0,0633	0,3036	103	18-1	0,0259	0,1241	145	25-1	0,0052	0,0247
20	4-2	0,0677	0,3384	62	11-2	0,2277	1,1385	104	18-2	0,0930	0,4650	146	25-2	0,0185	0,0927
21	4-3	0,0451	0,5412	63	11-3	0,1518	1,8216	105	18-3	0,0620	0,7440	147	25-3	0,0124	0,1482
22	4-4	0,0320	0,0541	64	11-4	0,1075	0,1822	106	18-4	0,0440	0,0744	148	25-4	0,0088	0,0148
23	4-5	0,0113	0,0180	65	11-5	0,0380	0,0607	107	18-5	0,0155	0,0248	149	25-5	0,0031	0,0049
24	4-6	0,0193	0,0966	66	11-6	0,0650	0,3252	108	18-6	0,0266	0,1329	150	25-6	0,0053	0,0264
25	5-1	0,0290	0,1390	67	12-1	0,0647	0,3106	109	19-1	0,0153	0,0732	151	26-1	0,0024	0,0115
26	5-2	0,1042	0,5208	68	12-2	0,2329	1,1643	110	19-2	0,0549	0,2745	152	26-2	0,0086	0,0432
27	5-3	0,0695	0,8334	69	12-3	0,1553	1,8630	111	19-3	0,0366	0,4392	153	26-3	0,0058	0,0690
28	5-4	0,0492	0,0834	70	12-4	0,1100	0,1863	112	19-4	0,0259	0,0439	154	26-4	0,0041	0,0069
29	5-5	0,0174	0,0278	71	12-5	0,0388	0,0621	113	19-5	0,0092	0,0146	155	26-5	0,0014	0,0023
30	5-6	0,0298	0,1488	72	12-6	0,0665	0,3327	114	19-6	0,0157	0,0783	156	26-6	0,0025	0,0123
31	6-1	0,0181	0,0866	73	13-1	0,0802	0,3847	115	20-1	0,0076	0,0365	157	27-1	0,0028	0,0134
32	6-2	0,0650	0,3249	74	13-2	0,2885	1,4427	116	20-2	0,0274	0,1371	158	27-2	0,0101	0,0504
33	6-3	0,0434	0,5202	75	13-3	0,1924	2,3082	117	20-3	0,0183	0,2190	159	27-3	0,0068	0,0810
34	6-4	0,0307	0,0520	76	13-4	0,1363	0,2308	118	20-4	0,0129	0,0219	160	27-4	0,0048	0,0081
35	6-5	0,0108	0,0173	77	13-5	0,0481	0,0769	119	20-5	0,0046	0,0073	161	27-5	0,0017	0,0027
36	6-6	0,0185	0,0927	78	13-6	0,0824	0,4122	120	20-6	0,0078	0,0390	162	27-6	0,0029	0,0144
37	7-1	0,0203	0,0972	79	14-1	0,0268	0,1286	121	21-1	0,0436	0,2093	163	28-1	0,0018	0,0084
38	7-2	0,0730	0,3648	80	14-2	0,0964	0,4821	122	21-2	0,1570	0,7848	164	28-2	0,0062	0,0312
39	7-3	0,0487	0,5838	81	14-3	0,0643	0,7710	123	21-3	0,1047	1,2558	165	28-3	0,0042	0,0498
40	7-4	0,0344	0,0583	82	14-4	0,0456	0,0772	124	21-4	0,0741	0,1256	166	28-4	0,0030	0,0050
41	7-5	0,0122	0,0194	83	14-5	0,0161	0,0257	125	21-5	0,0262	0,0419	167	28-5	0,0011	0,0017
42	7-6	0,0208	0,1041	84	14-6	0,0275	0,1377	126	21-6	0,0448	0,2241	168	28-6	0,0018	0,0090

Table 4 The supply point information

No	Name	Type	Position
1	Liangxiang Hospital of Fangshan District	Hospital	116,146981, 39,743042
2	Beijing Yanhua Hospital	Hospital	115,957936, 39,733228
3	Doudian Central Hospital of Fangshan District	Supply	116,071540, 39,654030
4	Fangshan District Changyang Community Health Service Center	Supply	116,219578, 39,772738
5	Beijing Shuokang Medical Device Co., Ltd.	Supplier	116,094966, 39,747560
6	Beijing Jiuhel Pharmaceutical Co., Ltd.	Enterprise	116,089098, 39,654113

Table 5 The supply information

No	SPN	SN	Weight / t	No	SPN	SN	Weight / t	No	SPN	SN	Weight / t	No	SPN	SN	Weight / t
1	1	1	1,93	10	2	4	0,65	19	4	1	1,46	28	5	4	2,11
2	1	2	6,67	11	2	5	0,37	20	4	2	5,51	29	5	5	0,75
3	1	3	4,72	12	2	6	0,36	21	4	3	3,88	30	5	6	1,44
4	1	4	3,28	13	3	1	1,43	22	4	4	2,68	31	6	1	0,23
5	1	5	1,12	14	3	2	5,32	23	4	5	0,92	32	6	2	0,98
6	1	6	1,89	15	3	3	3,28	24	4	6	1,45	33	6	3	0,61
7	2	1	0,37	16	3	4	2,25	25	5	1	1,35	34	6	4	0,46
8	2	2	1,33	17	3	5	0,84	26	5	2	4,38	35	6	5	0,15
9	2	3	0,77	18	3	6	1,53	27	5	3	3,17	36	6	6	0,26

Table 6 The vehicle information

No	Name	Type	Load / t	$L \times W \times H$ / m	Speed / km/h	Position	Available time / h
1	Vehicle 1	Owned	4,5	4,2 × 2,0 × 2,0	60	116,137009, 39,728670	0,30
2	Vehicle 2	Owned	5,0	5,2 × 2,1 × 2,1	59	116,137009, 39,728670	0,30
3	Vehicle 3	Social	6,0	6,2 × 2,3 × 2,0	58	116,151655, 39,750781	0,25
4	Vehicle 4	Social	8,0	6,8 × 2,3 × 2,4	55	116,151655, 39,750781	0,25

5.2.2 Experimental Design

The PSO [25] and the MPPSO [20] is selected for comparative experiments. All the selected algorithms are programmed in MATLAB. Each algorithm is applied to solve the case and runs independently 30 times. The software environment is the R2024b version of MATLAB. The hardware environment of the numerical experiment is an Intel (R) Core (TM) i7-8550UCPU with x64 processor, 1.80 GHz 1.99 GHz and 16 GB memory.

5.2.3 Parameter Settings

The parameters are set according to the literature or experiment. The *ph*, *pcf*, *g*, *sllu*, and *VC* are set according

to literature [20]. The *beta_max* and *beta_min* are set according to literature [22]. The *a* is set according to literature [23]. The learning factor *c*₁ and *c*₂, and compression factor *w* are set according to literature [25]. The *max_ite* and *Ns* are set according to the experiment. The parameters of the algorithms are shown in Tab 7.

Table 7 The parameters of the algorithms

No	Name	Value	No	Name	Value
1	<i>Ns</i>	100	8	<i>beta_min</i>	0,5
2	<i>ph</i>	2	9	<i>a</i>	8
3	<i>pcf</i>	5	10	<i>max_ite</i>	500
4	<i>g</i>	2	11	<i>c</i> ₁	2,8
5	<i>sllu</i>	min(10, <i>Nd</i>)	12	<i>c</i> ₂	1,3
6	<i>VC</i>	10	13	<i>w</i>	0,7298
7	<i>beta_max</i>	1			

5.2.4 Experimental Result

Fig. 5 shows the average convergence of the algorithm for the optimal solution of the case. The IMPPSO, MPPSO, PSO can quickly converge to the optimal solution of the problem, and the average convergence curves of the three versions of PSO maintain a downward trend, which means that increasing the number of iterations can further improve their performance. Compared with MPPSO and PSO, the IMPPSO has faster convergence velocity and higher performance, which is beneficial to avoid the algorithm falling into local optimum.

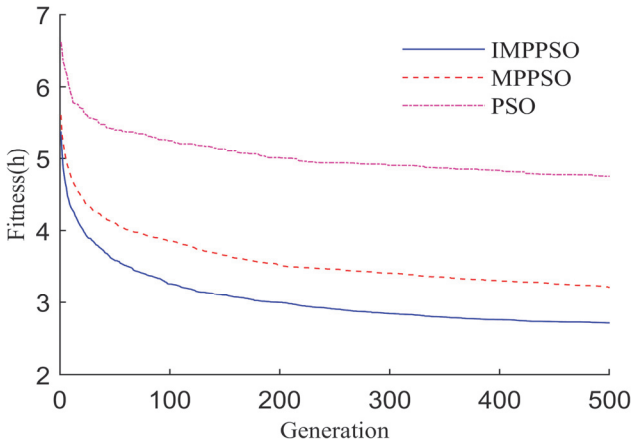


Figure 5 The average convergence of the algorithms for the optimal solution

Tab. 8 shows the performance comparison of IMPPSO, MPPSO and PSO for the fitness. The minimum, maximum and mean value of IMPPSO are smaller than those of MPPSO and PSO, which means that IMPPSO can give a better solution. Moreover, the standard error of IMPPSO is smaller than that of MPPSO and PSO, which means that its robustness is better. Fig. 6 shows the statistical analysis of the algorithms for the fitness. Three versions of PSO show very good robustness. Compared with MPPSO and PSO, the fitness value obtained by IMPPSO is not only smaller in mean value, but also smaller in dispersion and more uniform in distribution. The average fitness obtained by IMPPSO is 15,58% and 42,95% better than that of MPPSO, and PSO, respectively.

Table 8 The computational statistics of the algorithms for the fitness

Name	Minimum	Maximum	Mean	Std
IMPPSO	2,64	2,78	2,71	0,03
MPPSO	3	3,43	3,21	0,11
PSO	4,3	5,28	4,75	0,28

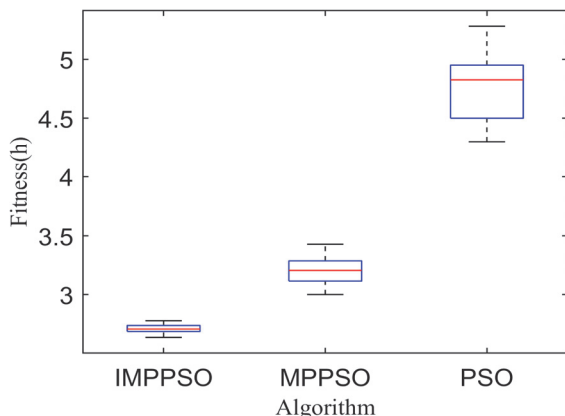


Figure 6 The statistical analysis of the algorithms for the fitness

Fig. 7 shows the Gantt chart of affected points for the case with IMPPSO. The figure shows the waiting allocation time and the waiting time for the transfer of emergency medical supplies of each affected point for the optimal solution obtained by IMPPSO.

Fig. 8 shows the statistical analysis of the algorithms for the running time. Although the running time of IMPPSO is slightly longer than that of MPPSO and PSO, it still finds a better sub-optimal solution than MPPSO and PSO within a reasonable time, and significantly improves the robustness of the solution within an acceptable time.

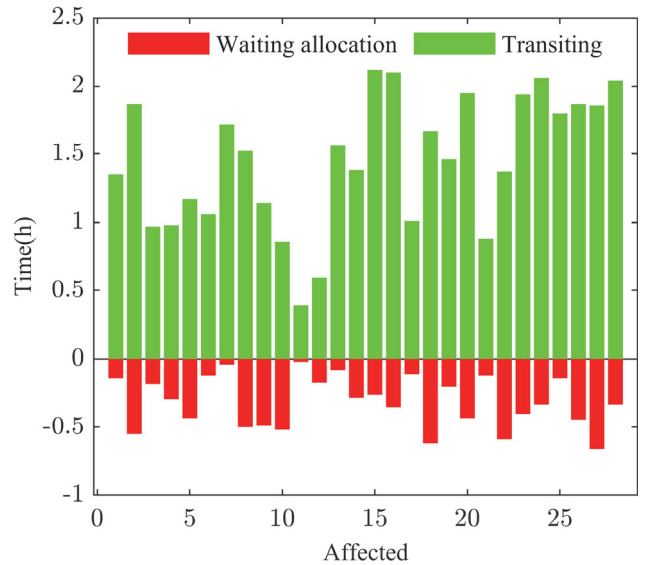


Figure 7 The Gantt chart of affected points for the case with IMPPSO

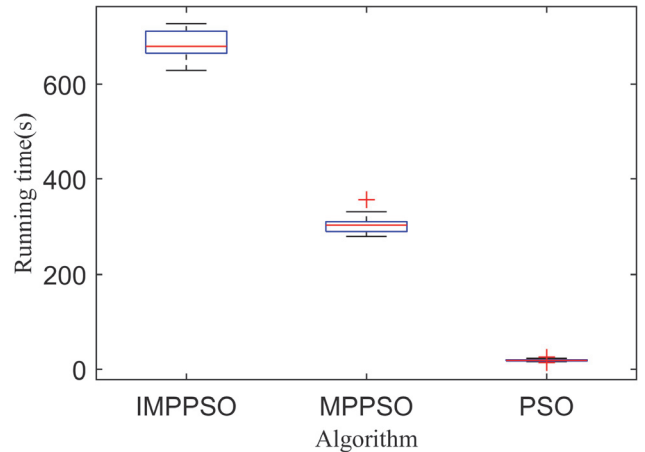


Figure 8 The statistical analysis of the algorithms for the running time

6 CONCLUSION

The collaborative optimization of loading and scheduling of emergency medical supplies is of great significance to emergency medical rescue. To solve this combinatorial optimization problem, the collaborative system of loading and scheduling of emergency medical supplies in public emergency is proposed. Considering each affected point's waiting time and affected level, and the conflict time of loading and unloading, a collaborative optimization model for emergency medical supplies loading and scheduling is constructed. Based on MPPSO, the IMPPSO is designed by selecting sub-dimensions randomly, introducing the contraction expansion coefficient and mutation operation, generating random

numbers by the Tent Chaotic Map and handling constraints, which is used to solve the constructed collaborative optimization model through the designed solution. Finally, the effectiveness of the proposed method is verified by numerical experiments.

The integration of the collaborative system and the government emergency management platform can realize the collaborative scheduling of emergency medical supplies, which is in line with the strategic direction of intelligent emergency. Therefore, the emergency medical management department, first, should establish emergency medical supplies scheduling standards and fair protection mechanism. Secondly, it is necessary to speed up the development of intelligent scheduling system. Finally, it is also necessary to use digital technology to optimize the dynamic allocation mechanism. Thereby, the foundation of national security and social stability can be consolidated to reduce the losses and even casualties of the affected people.

The designed algorithm obtains a better solution in a relatively reasonable time, but the running time is longer, which is worth further optimization. Moreover, it is also necessary to explore the influence of key parameters of the algorithm. Additionally, the practicality of the case is also worth further deepening. Furthermore, it should also be explored to evaluate the robustness of the model in the case of large-scale deployment and sudden supply chain disruptions.

Acknowledgements

This work was supported by the Beijing Social Science Foundation [Grant number 21GLC044].

7 REFERENCES

- [1] Xue, L. & Zhong, K. (2005). Classification of types, levels and stages for emergencies : managerial foundation of government emergency response system. *Chinese Public Administration*, 102-107.
- [2] Wu, X., Wu, F., Li, M. & Ji, Y. (2021). Optimal Model of Emergency Medical Supplies Stowage under Traffic Control during the Initial Period of the Epidemic Based on Characteristics Analysis of COVID-19 Epidemic. *Mathematical Problems in Engineering*, 2021, 1-14. <https://doi.org/10.1155/2021/5578047>
- [3] Li, X., Lu, G., Hu, Q.-M., & Lu, J. (2023). Integrated Design of Emergency Medical and Material Distribution Networks During the Epidemic Outbreak Period. *IEEE Access*, 11, 22404-22417. <https://doi.org/10.1109/ACCESS.2023.3252546>
- [4] Li, J., Fu, H., Lai, K. K., & Ram, B. (2022). Optimization of Multi-Objective Mobile Emergency Material Allocation for Sudden Disasters. *Frontiers in Public Health*, 10. <https://doi.org/10.3389/fpubh.2022.927241>
- [5] Hu B, Jiang G, Yao X, Chen W, Yue T, Zhao Qi, & Wen Z. (2023). Allocation of emergency medical resources for epidemic diseases considering the heterogeneity of epidemic areas. *Frontiers in Public Health*, 992197(11), 1-10. <https://doi.org/10.3389/fpubh.2023.992197>
- [6] Yuan, Y., Du, L., Luo, L., & Cui, L. (2023). Allocation strategy of medical supplies during a public health emergency: a tripartite evolutionary game perspective. *Scientific Reports*, 13(1), 9571. <https://doi.org/10.1038/s41598-023-36000-y>
- [7] Wang, Y., Lyu, M., & Sun, B. (2024). Emergency resource allocation considering the heterogeneity of affected areas during the COVID-19 pandemic in China. *Humanities and Social Sciences Communications*, 11(1), 225. <https://doi.org/10.1057/s41599-024-02712-3>
- [8] Moura, A., Pinto, T., Alves, C., & Valério de Carvalho, J. (2023). A Metaheuristic Approach to the Integration of Three-Dimensional Bin Packing Problem and Vehicle Routing Problem with Simultaneous Delivery and Pickup. *Mathematics*, 11(3). <https://doi.org/10.3390/math11030713>
- [9] Zhao, Y. & Zhang, L. (2022). An Advanced Study of Urban Emergency Medical Equipment Logistics Distribution for Different Levels of Urgency Demand. *International Journal of Environmental Research and Public Health*, 19(18), 11264. <https://doi.org/10.3390/ijerph191811264>
- [10] An, J. & Zhuo, B. (2023). Transportation and Reserve of Emergency Medical Supplies during Public Health Events. *Applied Sciences*, 13(18). <https://doi.org/10.3390/app131810171>
- [11] Peng, Z., Wang, C., Xu, W., & Zhang, J. (2022). Research on Location-Routing Problem of Maritime Emergency Materials Distribution Based on Bi-Level Programming. *Mathematics*, 10(8). <https://doi.org/10.3390/math10081243>
- [12] Wang, X., Liang, Z., & Zhu, K. (2021). Markov Decision Model of Emergency Medical Supply Scheduling in Public Health Emergencies of Infectious Diseases. *International Journal of Computational Intelligence Systems*, 14(1), 1155. <https://doi.org/10.2991/ijcis.d.210222.002>
- [13] Liu, J., Bai, J., & Wu, D. (2021). Medical supplies scheduling in major public health emergencies. *Transportation Research Part E: Logistics and Transportation Review*, 154, 102464. <https://doi.org/10.1016/j.tre.2021.102464>
- [14] Xia, H., Sun, Z., Wang, Y., Zhang, J. Z., Kamal, M. M., Jasimuddin, S. M., & Islam, N. (2025). Emergency medical supplies scheduling during public health emergencies: algorithm design based on AI techniques. *International Journal of Production Research*, 63(2), 628-650. <https://doi.org/10.1080/00207543.2023.2267680>
- [15] Marković, D., Stanković, A., Marinković, D., & Pamučar, D. (2024). Metaheuristic Algorithms for the Optimization of Integrated Production Scheduling and Vehicle Routing Problems in Supply Chains. *TehnickiVjesnik - Technical Gazette*, 31(3), 800-807. <https://doi.org/10.17559/TV-20240207001318>
- [16] Chen, M. (2023). RETRACTED ARTICLE: Optimal path planning and data simulation of emergency material distribution based on improved neural network algorithm. *Soft Computing*, 27(9), 5995-6005. <https://doi.org/10.1007/s00500-023-08073-4>
- [17] Zhang, J. & Lin, X. (2020). Research on Vehicle Routes Optimization for Emergency Materials Distribution. *Journal of Physics: Conference Series*, 1622(1), 012075. <https://doi.org/10.1088/1742-6596/1622/1/012075>
- [18] Zhao, X., Peng, B., Zheng, C., & Wan, A. (2023). Emergency Medical Resources Allocation of Periphery for Epidemic Areas: Based on Infectious Diseases Spatial-Temporal Transmission Path. *Complexity*, 2023, 1-13. <https://doi.org/10.1155/2023/8841451>
- [19] Ruan, J. H., Wang, X. P., Chan, F. T. S., & Shi, Y. (2016). Optimizing the intermodal transportation of emergency medical supplies using balanced fuzzy clustering. *International Journal of Production Research*, 54(14), 4368-4386. <https://doi.org/10.1080/00207543.2016.1174344>
- [20] Al-Kazemi, B. S. N. (2002). *Multiphase particle swarm optimization*. Syracuse University.
- [21] Zhang, H. (2019). *Research on Multi-objective Swarm Intelligence Algorithms for Door-to-door Railway Freight Transportation Routing Design*. Beijing Jiaotong University.
- [22] Singh, M. R. & Mahapatra, S. S. (2016). A quantum behaved particle swarm optimization for flexible job shop scheduling. *Computers & Industrial Engineering*, 93, 36-44.

<https://doi.org/10.1016/j.cie.2015.12.004>

- [23] Zhang, Y., Gong, D.-W., & Ding, Z. (2012). A bare-bones multi-objective particle swarm optimization algorithm for environmental/economic dispatch. *Information Sciences*, 192, 213-227. <https://doi.org/10.1016/j.ins.2011.06.004>
- [24] Marinakis, Y. & Marinaki, M. (2012). A Hybrid Particle Swarm Optimization Algorithm for the Open Vehicle Routing Problem. *8th International Conference, ANTS 2012*, 180-187. https://doi.org/10.1007/978-3-642-32650-9_16
- [25] Kennedy, J. & Eberhart, R. (1995). Particle swarm optimization. *Proceedings of ICNN'95 - International Conference on Neural Networks*, 4, 1942-1948. <https://doi.org/10.1109/ICNN.1995.488968>

Contact information:

Hankun ZHANG, PhD
Business School,
Beijing Technology and Business University, Beijing 100048, China
E-mail: zhanghankun@btbu.edu.cn

Jiayu SHEN
Business School,
Beijing Technology and Business University, Beijing 100048, China
E-mail: 13621114503@163.com

Jianna YANG
Business School,
Beijing Technology and Business University, Beijing 100048, China
E-mail: yyy10102001@163.com

Robert OJSTERSEK, PhD, Assistant Professor
(Corresponding author)
Faculty of Mechanical Engineering,
University of Maribor, 2000 Maribor, Slovenia
E-mail: robert.ojstersek@um.si