ISSN: 2688-9323

Route Optimization of Emergency Material Distribution Vehicle under Uncertain Demand

Qian Tang*, Gengjun Gao

Shanghai Maritime University, Logistics Research Center, Shanghai 201306, China

Abstract

The demand for emergency supplies in epidemic areas with sudden epidemics is uncertain. The optimization of the delivery vehicle path of emergency supplies in epidemic areas directly affects the efficiency of emergency logistics. In order to ensure that emergency supplies are quickly and reasonably delivered to the disaster-stricken point, this article assumes that the demand for supplies is randomly compliant with the normal distribution. Establish a dual-objective model with the least amount of unsatisfied materials in the epidemic area and the lowest total cost of emergency transportation, and use the hybrid particle swarm algorithm to design the model solution method. Through the analysis of calculation examples, the calculation results are obtained in a short time. The experimental results prove the effectiveness and feasibility of the vehicle route optimization model and algorithm for emergency material distribution.

Keywords

Emergency Supplies; Uncertain Demand; Vehicle Path Optimization; Hybrid Particle Swarm Algorithm.

1. Introduction

The large-scale outbreak of public health incidents will bring huge loss of life and property safety to the public. For example, the SARS virus in 2003, the bird flu in 2005, the COVID-19 in 2019, and so on. Public health emergencies that cause huge economic losses are followed by serious harm to the people's psychology, which is not conducive to the stable development of society. For infectious diseases that can be spread through droplets and contact, the impact is even more serious. At this time, the necessary isolation measures are one of the effective means to deal with the epidemic. The epidemic area is isolated from the outside world, and the emergency supplies in the isolation area are required. It is urgent and the demand is huge. Under such conditions, the quantity and type of emergency supplies are often uncertain, so the difficulty of dispatching is also increasing. At this time, how to scientifically plan the route of emergency delivery vehicles has become an important research topic for improving the efficiency of emergency delivery after the outbreak. In addition, the high-efficiency and high-satisfaction distribution of emergency supplies in the epidemic area can guarantee the basic epidemic prevention needs of the people in the epidemic area and alleviate the people's panic.

Cart[1] first clarified the concept of emergency logistics in 1992, and there have been more and more relevant researches on emergency logistics. Wang et al. (2014) [2] studied the open vehicle routing problem of emergency logistics under the determined demand; Liu Lei (2014) [3] took into account the characteristics of strong timeliness and indispensability of medical supplies, considering the known demand And other factors, establish a multi-objective model, and use improved genetic algorithm to optimize; Arora (2010) [4] proposed a cost-constrained medical emergency material allocation model, and took the rescue success rate at the demand point as the maximum optimization goal; Lin (2011) [5] minimized the shortage of materials and the satisfaction of material demand The degree difference is the goal to construct an optimization model to obtain the satisfaction degree of material distribution in the emergency rescue process; Cheng Birong et al. (2016)[6] proposed that the material demand obeys the normal distribution, established an optimization model for the emergency logistics vehicle routing problem in a random demand environment, used an improved nearest allocation combined with the average distance method, and designed a genetic algorithm to illustrate the effectiveness of the model; Sun Huali et al. (2018)[7] quantified the path risk into path capacity risk, path damage risk and path complexity in view of the uncertainty of the material demand at the disaster site, and established an optimization model based on robust optimization theory; Zhang Xingwen (2019)[8] takes into account both efficiency and fairness, considering the uncertainty and fairness of the material demand at the disaster site, and constructs a multi-objective vehicle routing problem optimization model with the least total transportation time and the greatest difference in material demand satisfaction rate; Zhao Tong et al. (2010) [9] studied the route optimization problem of emergency aid delivery vehicles with time windows; Lu Wei et al. (2020) [10] Comprehensively consider the shortest total delay time under the constraints of soft and hard time windows, the smallest penalty cost of soft time windows, and the least number of emergency supplies vehicle delivery route models that do not meet the hard time windows; Yuan Shijun et al. (2019) [11] With the goal of minimizing the loss caused by the delayed satisfaction of all demand points and all items, construct a mathematical model and use particle swarm optimization to optimize; Wu Cong (2015) et al. [12] improved the learning coefficients on the basis of the standard particle swarm algorithm, so that c1 decreases linearly with the evolutionary algebra, and c2 increases linearly, so that the diversity of particles increases in the early stage and gradually converges in the later stage, so as to obtain more Good global search results; Li Jin et al. (2015) [13] modified the standard search method on the basis of the taboo search method, so that the minimum cost is the goal in the search process and the influence of vehicle load and speed is considered at the same time. Gao Na et al. (2017) [14] used nonlinear inertia weights and added a variable neighborhood search algorithm to make the improved algorithm quickly jump out of local convergence, and finally obtain better path search results.

The suddenness and uncertainty of the epidemic will inevitably lead to uncertainty in the demand for emergency supplies in the disaster-stricken areas, and the demand for supplies from the people in the disaster-stricken areas is imminent. According to the characteristics of the sudden infectious disease, this article responds to the requirements of rapid distribution and solves the transportation problem of emergency supplies such as grain. Consider the vehicle route planning problem of minimizing the total cost of emergency logistics and distribution to the disaster-stricken point in the city and the minimum unmet demand. In the actual distribution process, due to objective conditions, it is difficult to meet the time window requirements of all demand points, and penalty costs will be incurred for transportation routes that do not meet the time window. The goal of minimizing the total cost in this article considers the fixed cost of the use of delivery vehicles, the variable cost that varies with the transportation distance, and the penalty cost of transportation time caused by the demand not being met within the time window, to quickly develop emergency logistics and distribution vehicle path optimization for epidemic areas. The plan provides a reasonable basis.

2. Problem Description and Symbol Description

2.1. Problem Description

When infectious diseases such as SARS and new crown pneumonia break out, the disaster-stricken areas must be isolated and controlled. At this time, emergency supplies such as food must be delivered to the isolated disaster-stricken areas within a certain period of time. After a

ISSN: 2688-9323

certain period of time, the needs of the victims may not be obtained. Satisfaction can easily cause panic. Due to the characteristics of the epidemic, quarantine measures must be taken, resulting in randomness in the demand for supplies in the quarantine area. The epidemic will not cause road damage, so the transportation time of vehicles on the road is relatively certain, but disinfection testing is required before entering the quarantine area. In view of the above problems, the vehicle path optimization problem to be studied is abstracted: This paper studies a group of disaster-stricken demand points, an emergency material distribution center, and different types of vehicles. The material requirements of each disaster-stricken point follow the normal distribution randomly; the transportation time of the vehicle on the road is determined. Vehicles depart from the distribution center and return to the distribution center after delivery; the cost of vehicle transportation is proportional to the transportation distance. Given a time window for each demand point, the time for materials to reach each demand point must be within the time window. If it is not met, penalty costs will be incurred. The delivery vehicles have capacity restrictions, and the demand at each disaster-stricken point is less than the load of the delivery vehicle, and each vehicle can complete more than one demand point transportation tasks alone.

2.2. Basic Assumptions

Through the previous analysis and elaboration, in order to facilitate the analysis and solution of the problem, first make assumptions about the related problems:

1) Assume that the demand for supplies at the disaster site is uncertain and obeys a normal distribution randomly;

2) The distribution center has a certain amount of emergency supplies, and only Can meet the needs in a specific time period;

3) There is no damage to the transportation road and there is no congestion, so the driving time of the vehicle is a definite value;

4) Each vehicle starts from the distribution center and returns to the distribution center after completing the distribution;

5) There are several different types of transportation vehicles in the distribution center, and the vehicles have capacity limitations;

6) The transportation task of each disaster-affected point is served by one vehicle, and each delivery vehicle can serve multiple disaster-affected points in the epidemic area.

2.3. Symbol Description

Define the following symbols and variables:

H : Represents a collection of demand points;

S : Represents emergency distribution center;

K : Represents a collection of delivery vehicles;

W : Indicates the capacity of the distribution center;

d_{ij}:Indicates the distance from demand point i to demand point j on the road;

q_i:Indicates the demand at demand point i, which obeys a normal distribution;

Q : Indicates the maximum load capacity of the delivery vehicle;

U_i:The quantity of materials in the distribution center that does not meet the demand point i;

ISSN: 2688-9323

ET_i: The earliest time that the vehicle is allowed to reach the demand point i;

LT_i: The latest time the vehicle is allowed to reach demand point i;

t_{ij}: Represents the vehicle travel time of vehicle k from demand point i to demand point j,which is a definite value;

t_i: Represents the service time at demand point i, including the time it takes for vehicles to enter the demand point for disinfection and epidemic prevention;

T_j: The actual time from the vehicle to the demand point j,$T_j = T_i + t_{ij} X_{ijk} + t_i$;

c_1: Fixed cost of driving;

c_2: Variable cost of driving;

c_3: The penalty parameter for not meeting the time window limit, expressed as the ratio of cost to time;

$$X_{ijk} = \begin{cases} 1 & \text{Vehicle k travels from demand point i to demand point j} \\ 0 & \text{Else} \end{cases}$$

$$Y_{ki} = \begin{cases} 1 & \text{Vehicle k passes through demand point i and delivers goods to demand point i} \\ 0 & \text{Else} \end{cases}$$

$$W_{ki} = \begin{cases} 1 & \text{Vehicle k is the demand point i to deliver emergency supplies} \\ 0 & \text{Else} \end{cases}$$

3. Model Building

According to the above, combined with the characteristics of the epidemic area, when the demand in the epidemic area is uncertain, consider vehicle path constraints, vehicle number constraints, time window constraints, and demand constraints to establish the minimum total cost of emergency transportation and the minimum unmet demand The dual target model:

$$Z = \min \sum_i U_i \quad Z = \min \sum_i U_i \tag{1}$$

$$C = \min \left\{ c_1 k + c_2 \sum_i \sum_j \sum_k d_{ij} X_{ijk} + c_3 \sum_i \left[\max\left(ET_i - T_i, 0\right) + \max(T_i - LT_i, 0) \right] \right\} \tag{2}$$

s.t.

$$\sum_k Y_{ki} = 1 \tag{3}$$

$$\sum_i X_{ijk} = Y_{kj} \tag{4}$$

$$\sum_j X_{ijk} = Y_{ki} \tag{5}$$

$$\sum_i \sum_k X_{Sjk} = \sum_j \sum_k X_{iSk} \le K \tag{6}$$

$$T_j = (t_{ij} + t_i + T_i) \times X_{ijk} \tag{7}$$

ISSN: 2688-9323

$$P\left\{\sum_i q_i \times Y_{ki} \le Q\right\} \ge \beta \tag{8}$$

$$W_{ki} + U_i - q_i \ge 0 \tag{9}$$

The objective function (1) represents the optimization of the unsatisfied demand at each demand point;

The objective function (2) represents the total cost of emergency transportation, including the fixed cost of using the vehicle, the variable cost of the vehicle, and the penalty cost of transportation time;

Constraints (3) (4) (5) is the vehicle path constraint, which means that each demand point can only be provided by one vehicle and only receive one service, and the vehicles arriving at the point and leaving the point are the same vehicle;

Constraint conditions (6) Constraint on the number of vehicles, which means that the number of vehicles used is less than the number of vehicles owned by the distribution center, and the vehicles depart from the distribution center for distribution tasks, and finally return to the distribution center;

Constraints (7) Time window constraints, which indicate the possibility of vehicles under the time window ordering;

Constraints (8) (9) Demand quantity constraint, which means that the probability that the quantity of materials delivered per vehicle is less than the capacity of the vehicle is not less than β, and the sum of the quantity of materials received at each demand point and the unsatisfied quantity shall not be less than the demand quantity at that point.

4. Model Solving

4.1. Model Conversion

The model constructed in this article is a multi-objective decision-making problem. Since how to deal with multi-objectives is not the focus of this article, the commonly used linear weighted summation method is used to convert multi-objectives into single-objectives [15][16]. In the case of not only meeting the requirements of minimizing unmet needs, but also minimizing the total cost, there is conflict between the two goals. In order to highlight the importance of emergency supplies to meet the needs of the people in the isolation point of the epidemic area, give each objective function. Assign a weight, and assign a relatively large weight to the objective function related to the demand.

Therefore, the following treatments are made for the goals of the dual-objective model:

$$F(x) = a * demand/\min U + b * \cos t/\min C \tag{10}$$

Let a and b be the weights of the two objective function values, where $0 \le a, b \le 1; a \ge b; a + b = 1$. min U and min C refer to the minimum unmet demand and the minimum cost. Is the minimum target value obtained when the goals of the model are the single goals of minimizing unsatisfied quantity and minimizing cost.

4.2. Algorithm Design

The particle swarm algorithm shows good searching ability when solving the optimization function. Through iterative optimization calculation, it can quickly find the approximate solution, and it has no special requirements on the search space. It has simple operation, fast convergence, and involves parameters. Few advantages. At the same time, the tabu search method has strong local search capabilities, which can be used to improve the shortcomings of standard particle swarm optimization that are easy to fall into local optimum and insufficient convergence performance [17]. Therefore, this paper uses hybrid particle swarm algorithm as a tool to solve the problem.

4.2.1. Chromosome Encoding and Decoding

The standard PSO algorithm uses real number coding, which cannot be directly applied to the solution of discrete problems. In order to overcome the coding deficiencies of the standard PSO algorithm, this paper constructs an encoding and decoding method based on random keys, so that the standard PSO algorithm can be applied to the optimization solution of the model in this paper.

Coding process: In order to overcome the shortcomings of real-number coding methods that cannot directly solve the discrete problem, this paper constructs a real-number coding and decoding method based on random keys. Assuming that the number of affected points in the epidemic area is M and the number of vehicles is K, the coding dimension of the problem is (M+K-1) ×1, and the dimension value range is [0,1].

Decoding process: using random key decoding, that is, the smallest value within the dimension range corresponds to 1, the second smallest value corresponds to 2, and so on, until all (M+K-1) in the interval [0,1] ×1 code is all mapped to a permutation on 1~(M+K-1), where 1~M represents the disaster point, and M+1~(M+K-1) represents the line division.

4.2.2. Constraint Handling

This paper uses the idea of penalty function to deal with constraints: if a chromosome does not meet the constraints, give it a certain penalty value, reflect the penalty value in the objective function, and reflect in the fitness function value, that is, add one to the objective function. A very large number reduces the fitness value and reduces the probability of selection, thereby adding a penalty value to the capacity constraints of the vehicle.

For the vehicle capacity constraint equation (8), let $H(x)=\sum_i Y_{ki}\Phi^{-1}(\beta)$, then the vehicle capacity constraint equation (16) is equivalent to $H(x)\leq Q$. So, add an item to the objective function: $g(x)=N\max(H(x)-Q,0)$, where N is a very large number.

4.2.3. Fitness Function

The particle swarm algorithm evaluates the goodness of the population through fitness. The more the fitness value meets the evaluation criteria, it means that the corresponding cancellation can meet the requirements of the expected goal. Currently, the objective function value is $\min W = F(x)+g(x)$ due to the minimum value of the objective function in this article, it is obtained as follows: fitness function value=objective function value, then the fitness function is $\min W$.

4.2.4. Local Optimization Process based on Tabu Search

Tabu search algorithm uses tabu technology to search for local best points. The tabu search method is a partial heuristic algorithm. By moving in each iteration, moving from the current solution to its neighborhood or a subset of the neighborhood to explore a better solution, and continuously improve the initial solution until the searched. The "optimal solution" has not changed so far. Since the search process allows the obtained solution to be an infeasible solution, it can avoid falling into a local optimal state [19] [20].

Step1: Given a taboo table, and select an initial solution γ; Step2: When the stop rule is met, stop the calculation and output the result; otherwise, select the candidate set that meets the nontaboo in the neighborhood N (γ) of γ; Choose a solution γ' with the best evaluation value among them; let γ become γ'. Update the taboo table and repeat STEP2.

4.2.5. Hybrid Particle Swarm Algorithm

Step1: Initialize the parameters and choose the real number encoding method based on random keys;

Step2: Initialize the population, generate the initial population, and calculate the fitness value of the population;

Step3: Update the history of each particle in the population and the current self-optimal solution and population.

Step4: Calculate the fitness value of the new particle;

Step5: For the optimal solution in the current population, use a local optimization process based on tabu search to update the particle;

Step6: If the algorithm reaches the maximum number of iterations, terminate. Search the process and output the current optimal solution; otherwise, go to Step3;

5. Numerical Analysis

Consider the distribution of emergency supplies after an epidemic occurs in a certain place. In the example, there are 10 disaster-stricken demand points and 1 emergency material distribution center. The distribution center has 5 distribution vehicles of the same model, and the unit transportation cost of the vehicles is 9 yuan/km. Table 1 shows the location information of the emergency distribution center. Table 2 shows the vehicle information. Table 3 shows the specific data information of the coordinates of each disaster-stricken point, the amount of materials required, and the service time of disinfection and epidemic prevention.

Table 1. Parameters of Emergency Center

Emergency distribution center	X coordinate/km	Y coordinate/km	Capacity/piece
0	55	80	650

Table 2. Parameters of delivery vehicles

Vehicle	Vehicle capacity/piece	Average driving speed/(km/h)
1-5	85	42

Table 3. Parameters of the disaster site

Disaster point	X coordinate/km	Y coordinate/km	Degree of need urgency	Service time/h	Demand obeys normal distribution
1	20	81	[0,126]	10	(40,8)
2	42	15	[0,139]	10	(20,3)
3	58	75	[0,160]	10	(60,11)
4	85	105	[0,105]	10	(18,4)
5	23	85	[0,118]	10	(12,9)
6	50	2	[0,148]	10	(36,12)
7	18	32	[0,157]	10	(32,16)
8	4	26	[0,111]	10	(54,10)
9	57	29	[0,168]	10	(14,6)
10	48	25	[0,130]	10	(8,10)

This article uses MATLAB software to write the program, set the number of iterations to be maxgen=250, the initial population number is N=200, and the adaptive crossover probability and adaptive mutation probability are Pc=0.7 and Pm=0.05, respectively. The objective function (1). The weight is set to a=0.8, and the weight of the objective function (2) is set to b=0.2. Finally, in order to verify the rationality and effectiveness of the model and algorithm, an example is given for verification. Run the program, and soon the program outputs the optimization results of the calculation example.

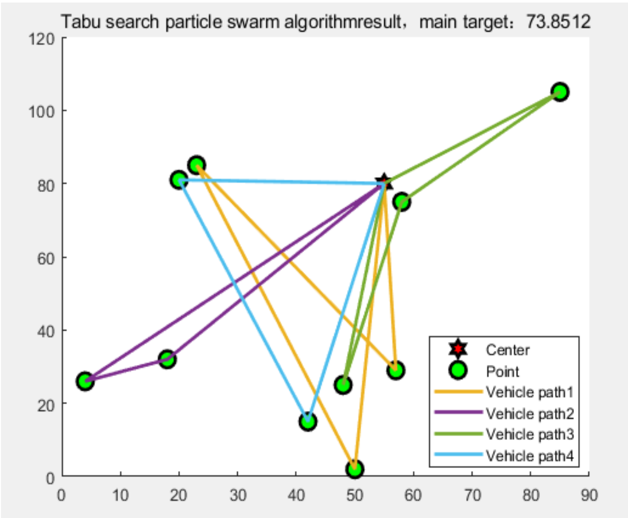

Figure 1. Vehicle route results

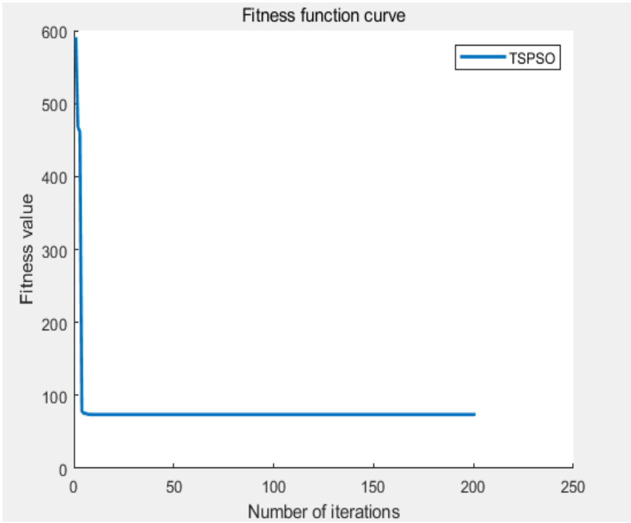

Figure 2. Target value convergence diagram

The program is run 30 times, the calculated result is stable, and the optimal objective function value is 73.8512. From the results of the vehicle routes in Figure 1, it can be concluded that the emergency center only needs to dispatch 4 vehicles to deliver emergency supplies. Each path meets the vehicle capacity limitation and time window requirements. The order in which each vehicle serves the disaster point is as follows:

Route 1 (vehicle 1):Emergency center-disaster site 9-disaster site 5-disaster site 6-Emergency center;

Route 2 (vehicle 2): Emergency center-disaster site 7-disaster site 8-Emergency center;

Route 3 (vehicle 4): Emergency Center-Disaster Point 1- Disaster Point 2- Emergency Center;

Route 4 (Vehicle 3):Emergency Center-Disaster Point 3-Disaster Point 4-Disaster Point 10-Emergency Center.

The target value convergence graph of the model is shown in Figure 2. It can be seen that the algorithm iteration speed is very fast, and the optimal solution is obtained between 300-400 generations, and the algorithm can meet the solution requirements of the model. In summary, the hybrid particle swarm algorithm based on tabu search local optimization in this paper does not have much difference in the solution results of this example. The optimization results are relatively stable and the time consumed is relatively short. Therefore, the solution effect is relatively good, which is verified the scheduling model in this paper is feasible.

6. Conclusion

This article first gives the problem description and modeling ideas. On the assumption that the material demand is randomly obeyed by the normal distribution, considering the relevant constraints such as capacity and time. Construct a dual-objective mathematical model with the smallest unsatisfied material demand and the lowest total emergency transportation cost in the epidemic area. Secondly, according to the special situation of emergency logistics vehicle scheduling, a hybrid particle swarm algorithm based on tabu search local optimization is designed, including particle coding method, fitness function, search process and determination of termination conditions. Then a numerical example is used to simulate the established model and algorithm to prove the effectiveness of the model and algorithm. The relevant research results can provide a scientific basis for effective vehicle dispatch during emergencies.

References

[1] Carter W N. Disaser Management：A Disaster Manager's Handbook [M]. Philippines: Asian Development Bank, 1992:5-25.

[2] Wang H , Du L , Ma S . Multi-objective open location-routing model with split delivery for optimized relief distribution in post-earthquake[J]. Transportation Research Part E: Logistics and Transportation Review, 2014, 69:160-179.

[3] Liu Lei. Research on emergency dispatch of medical supplies based on emergencies[D]. University of Nanhua, 2014.

[4] Arora H, Raghu T S,Vinze A, Resoure allocation for demand surge mitigation during disaster response [J].Decision Support Systems,2010,50(1):304-315.

[5] Lin Y H,Batta R,Rogerson P A, et al. A logistics model for emergency supply of critical items in the aftermath of a disaster[J]. Socio-Ecnomic Planning Sciences, 2011.45(4):132-145.

[6] Cheng Birong, Zhao Xiaobo, Qin Jin. Emergency logistics vehicle routing optimization model and algorithm considering insufficient supply [J]. Computer Application Research, 2016, 33(06): 1682-1685.

[7] Sun Huali, Cao Wenqian, Xue Yaofeng, Wang Xunqing. Uncertain emergency logistics positioning based on demand considering route risk-route problem[J]. Operations Research and Management, 2018, 27(07): 37-42.

[8] Zhang Xingwen. Multi-objective optimization model of fair distribution of emergency supplies under fuzzy conditions[J]. Logistics Technology, 2019, 42(05): 20-24.

[9] Zhao Tong, Fan Houming, Wang Guilin, Zhang Jingyao, Dong Guosong, Li Jiashu. Research on the route optimization model of emergency aid delivery vehicles with time windows[J]. Logistics Technology, 2010, 29(20): 63-65+68.

[10] Lu Wei, Li Zhihong, Ma Yaping, Zhao Xiangcheng, Ning Jingjing. Research on emergency material distribution vehicle path planning considering the demand time window of the disaster site[J]. China Work Safety Science and Technology, 2020, 16(03): 5-11.

[11] Yuan Shijun, Liang Ruiwei. Emergency logistics vehicle scheduling based on PSO algorithm[J]. Logistics Technology, 2019, 38(07): 89-95.

[12] Wu Cong, Yang Jianhui. Logistics distribution vehicle scheduling optimization based on improved particle swarm algorithm[J]. Computer Engineering and Applications, 2015, 51(13):259-262.

[13] Li Jin, Fu Peihua, Li Xiulin, et al. Research on Vehicle Routing Problem and Tabu Search Algorithm in Low Carbon Environment[J]. China Management Science, 2015, 23(10):98-106.

[14] Gao Na, Gao Gengjun, Li Xiaohong, Research on Pledged Material Delivery Route Based on PSO-VNS Algorithm[J]. Journal of Chongqing Normal University (Natural Science Edition), 2017.

[15] Zhu L, Gong Y, Xu Y, et al. Emergency relief routing models for injured victims considering equity and priority[J]. Annals of Operations Research, 2019, 283(1-2): 1573-1606.

[16] Sheu J B. Dynamic relief-demand management for emergency logistics operations under large-scale disasters[J]. Transportation Research Part E: Logistics & Transportation Review, 2010, 46(1): 1-17.

[17] Ou Yuehua. Research on optimization of cold chain distribution logistics vehicle scheduling for a dairy company[D]. South China University of Technology, 2018.

[18] Bean J C. Genetic Algorithms and Random Keys for Sequencing and Optimization[J]. Orsa Journal on Computing, 1994, 6:154-160.

ISSN: 2688-9323

[19] Hoong Chuin Lau, Melvyn Sim, Kwong Meng Teo. Vehicle routing problem with time windows and a limited number of vehicles[J]. European Journal of Operational Research, 2003, 148(3):559-569.
[20] Liao T Y. Tabu Search Algorithm for Dynamic Vehicle Routing Problems Under Real-Time Information[J]. Transportation Research Record Journal of the Transportation Research Board, 2004, 1882(1):140-149.