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Research on Community Intelligent Logistics UAV Scheduling Based on Intelligent Optimization Algorithm

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Abstract: "The last mile" is a key problem that needs to be solved urgently by major e-commerce companies, and also an important means to improve their competitiveness in e-commerce activities. In this paper, aiming at the problems existing in the current community intelligent logistics, from the perspective of the entire logistics system, combined with the actual distribution of logistics sites and distribution methods, we studied the scheduling problem of UAVs using different strategies when returning to the site after distribution. First, the UAV distribution time model is established, and then the model is solved with the minimum completion time of goods distribution as the goal. Finally, the feasibility of the algorithm is verified through simulation experiments, and the optimal scheduling strategy of UAV is given in combination with the actual operation, thus guiding e-commerce to build a reasonable intelligent logistics system.

Keywords: unmanned aerial vehicle, scheduling strategy, intelligent optimization algorithm

1 Introduction

With the development of information technology, the e-commerce industry, with the Internet as the carrier and diversified information technology as the support, has achieved prosperity and development, followed by a large number of packages waiting for distribution. For e-commerce enterprises, timely fulfillment of buyer orders and delivery is one of the core competitiveness of e-commerce enterprises. Since Amazon, the world's leading e-commerce company, first announced its home delivery plan for drones, major e-commerce companies have followed suit and started testing drone distribution. The UAV has the characteristics of fast flight speed and high flexibility. Under the influence of vehicle congestion and the COVID-19, the UAV distribution can meet the timeliness of distribution, and can also avoid the risk of COVID-19 transmission caused by centralized delivery, so it has a very high development prospect.

The "last mile" of logistics is the most important link to ensure the timeliness of express packages, and it is also the primary problem that major e-commerce companies need to solve. At present, the research and application of UAV distribution system is still in its infancy, and the related research results are relatively few, most of which focus on the planning of UAV distribution path. At present, the research on intelligent logistics still has the shortcomings of incomplete optimization of terminal link scheduling strategy and incomplete system establishment. Therefore, from the perspective of the entire intelligent logistics system, this paper optimizes and upgrades the entire distribution chain, and completes the following work:

(1) In this paper, a deterministic model for the shortest overall delivery time of UAV in the delivery environment is constructed, and the hybrid intelligent algorithm is used to solve the model.

(2) At the same time, considering the interference factors of UAV, such as the uncertainty of delivery time caused by customers not at home or going out temporarily, a time uncertainty model is constructed, and an intelligent algorithm is designed to solve the model.

(3) Through simulation experiment analysis, the UAV scheduling strategy with delivery time as the target is obtained, and then the scientific and reasonable UAV configuration guidance is given to e-commerce companies according to the number of UAVs and the number of stations.

The structure of this paper is as follows. Chapter 2 analyzes the research achievements of other researchers, their research directions and existing technical weaknesses. The third chapter models and analyzes the distribution strategy of intelligent logistics and terminal UAV through intelligent optimization algorithm. In the fourth

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chapter, the algorithm is simulated, and the scientific distribution strategy is obtained through experiments and data analysis. Finally, the fifth chapter draws a conclusion: in view of the technical deficiencies of this research, further research plans and new research directions are proposed.

2 Related Work

The concept of UAV distribution was first proposed by Amazon, and then applied and promoted by major e-commerce enterprises. It is a new distribution model that has emerged in the past decade and is gradually attracting the research interest of scholars.

R. G. M. Saleu studied the parallel scheduling problem of multiple UAVs and logistics trucks. The modeling method refers to the traveling salesman model, and designed a mixed meta heuristic algorithm model. The goal is to shorten the delivery time, which has certain reference significance for UAV scheduling [1]. H. Jung and J. Kim studied the UAV package delivery scheme for sparsely populated areas, such as mountain areas, and proposed a UAV scheduling model. At the same time, robust optimization was used to consider the impact of wind speed on UAVs. Although different from community distribution, the impact of wind speed also has reference value for this paper [2]. Giovanni Campuzano for the last kilometer of logistics, the dynamic UAV scheduling problem is studied, the factors of delayed delivery of UAVs are considered, and a Markov decision model is designed [3]. Grzegora presented problem concerns the route planning of a UAV fleet carrying out deliveries to spatially dispersed customers in a highly dynamic and unpredictable environment within a specified timeframe [4]. Qin Chen proposed an improved ant colony algorithm based on tabu search for the larger scale UAV scheduling problem. The purpose is to optimize the number of UAVs after the scale and the calculation time of the algorithm. However, the scheduling optimization strategy itself has not been described too much [5]. Honghai Zhang, aiming at the UAV scheduling problem in the urban environment, gets the comprehensive priority by weight distribution according to the priority of goods, logistics companies and delivery time, and then establishes the deployment model, with the optimization goal of flight cost and the optimization object of each priority weight [6]. Meanwhile Zhang Honghai used improved genetic algorithm to optimize the takeoff and landing site selection in the UAV distribution process, taking logistics characteristics, UAV performance, airspace environment as parameters, aiming at the UAV takeoff and landing site selection problem, and also studied the single link of scheduling [7]. Dan Yuan regarded UAV scheduling as a traveling salesman problem. By using the combination model of simulated annealing model and exhaustive method, he did not study the terminal problem of a single UAV for the optimal distribution route of trucks and UAVs under different circumstances [8].

3 Model Establishment and Algorithm Solving Process

This paper first constructs an intelligent operation system, which includes a community. There are multiple logistics sites in the community, as well as sites for UAV battery replacement and battery charging. The UAV completes the loading of packages at the logistics site, then flies to the designated target for delivery, finally returns to the site according to the UAV distribution strategy of the system, and then delivers the next task. This is the complete process for UAV to complete a distribution. For the whole system time, there are two options after the UAV has delivered the package: one is to return to the designated station and wait for the next task; The second is to fly back to the site with tasks according to the order tasks queued by the system. Delivery timeliness is the priority service objective of e-commerce, so this paper selects the optimal return scheme of UAV to minimize the delivery time. Two time models are considered respectively: UAV completes delivery according to expectations and steps, that is, time determination model; Disturbed by uncertain factors, the UAV did not complete the delivery after flying out [9].

3.1 The Establishment of Time Model for Distribution Determination

For the target community, since the community express stations and their distribution have been determined, the UAV is relatively certain in the process of delivery and delivery, the process of returning to the station, and the time of battery charging and changing. This section mainly studies how to complete the UAV scheduling under the determined time model. The model solution is shown in Fig. 1.

Combined with the actual situation and management status, this paper only considers that the UAV uses battery replacement to recharge the power, while the battery is charged uniformly. The power supply model of the UAV is shown in Fig. 2.

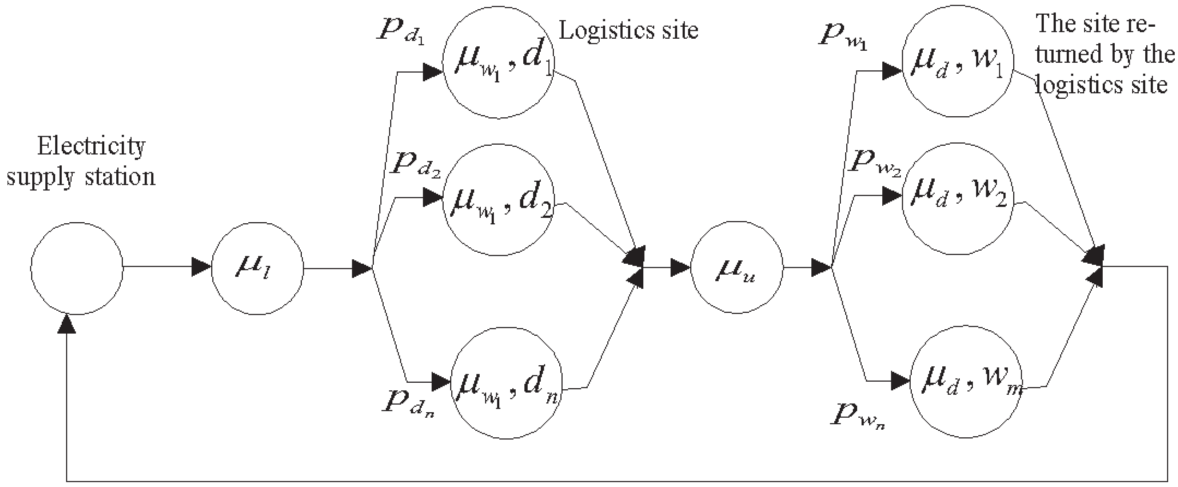


Fig. 1. Graph of UAV distribution time determination model

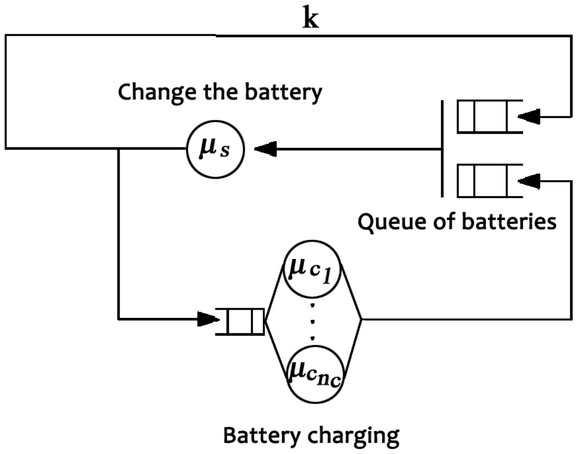


Fig. 2. UAV power supply graph

In the model, each parameter is quantified, assuming that logistics station w_i has N_D^{wi} UAVs and uses N_D^{wi} UAVs to complete the order distribution task assigned to the logistics station with the highest probability. The initial value of UAV quantity N_D^{wi} owned by each logistics station is determined according to the actual demand of each logistics station every day. On the premise of meeting the current order arrangement, the fastest delivery time of the community terminal delivery system is calculated based on the deterministic time model, and the heuristic domain search algorithm is used to solve the problem, so that the system time is optimal.

3.2 Model Solving Method and Process

In this paper, the approximate mean method is used to analyze the optimal time $T(N_D)$ of the system for the battery replacement strategy. The time determination model established in 3.1 is analyzed by decomposition, and the steps are as follows:

(1) Simplify the model representing the battery exchange process in Fig. 2 to a time network model containing k customers, and calculate the time $T_{bs}(k)$ of the time network model.

(2) A complete supply time of the battery supply strategy in the model depends on the service of battery replacement at the supply station, and the service rate of the supply station is $u_b^{w_i} = 1/T_{bs}(k), i = 1, 2, \cdots, m$.

(3) The approximate mean algorithm is used to solve the updated time network model, and the maximum time $T(N_D)$ of the system is obtained.

Fig. 2 shows the integrated UAV power supply model, which includes k UAVs. The state variable is (N_s, N_C), N_s is the number of u_s UAVs for battery exchange service, and N_c is the number of batteries at the battery service point. If the number k of UAVs in the time network is less than the number n_b of swapped batteries, by solving the Markov chain [10], the state probability and the time of the model can be obtained. The formula is as follows:

$$T_{bs}(k) = \sum_{N_c}^{n_b} \pi(N_s, N_c) \cdot \overline{N_c} \cdot u_c . \quad (1)$$

$$\overline{N_c} = \overline{n_b - i} = \min(n_b - i, n_c) . \quad (2)$$

After getting the model time $T_{bs}(k)$ representing the battery exchange process, replace the model with a service point, and the service rate of the service point is $u_b = 1/T_{bs}(k), k = 1, 2, \cdots, N_D$. Embed the service point into the time network model of the system, and calculate the maximum time $T(N_D)$ of the system through the approximate mean algorithm.

3.3 Heuristic Assignment Strategy

In this paper, genetic algorithm is selected to solve the model, and the overall time of UAV distribution is optimized by the goal of maximum package distribution in the UAV distribution process. The basic idea of the algorithm is to continuously reduce the time of UAV from power supply to cargo loading to distribution, and correspondingly increase the number of UAV deliveries, iterating several times, until the distribution time of the system can no longer be improved, then stop iterating. In order to prevent the calculation time from being too long, this paper sets a stop criterion, that is, the maximum number of iterations. When the number of iterations reaches the maximum number of iterations, or the historical optimal value repeats for more than N consecutive times, the algorithm stops and outputs the optimal value.

The pseudo code of the algorithm is as follows:

Table 1. The pseudo code of the algorithm

Algorithm 1. Optimization algorithm
1: Initialization
2: The probability of UAV returning to each logistics site is $p_w = \{p_{w_1}^c, p_{w_2}^c, \cdots, p_{w_m}^c\}$
3: p_w is introduced into the time network model built for the system, and the maximum time $T(p_w)$ is calculated by the approximation method.
4: Based on the calculation results of approximate value method, the expected time for power recovery of each station is obtained.
5: Let iteration marker variable $N_{ite} = 1$, and give a maximum iteration number MAX_{ite}.
6: Determine the time adjustment ratio ε of UAV returning to the logistics site in each iteration.

7: Iteration:
8: while $N_{ite} \le MAX_{ite}$ do
9: Find the logistics site $\max_i ET_b^{w_i}\left(N_D\right)$ with the largest delivery time of unmanned electromechanical quantity, and mark the probability of UAV returning to the station with $p_{w_i}^{\max}$;Find the logistics site $\min_i ET_b^{w_i}\left(N_D\right)$ with the shortest delivery time of UAV and mark the probability of UAV returning to the station with $p_{w_i}^{\min}$.
10: $p_{w_i}^{\max} = p_{w_i}^{\max} - \varepsilon\% \cdot p_{w_i}^{\min}$ and $p_{w_i}^{\min} = p_{w_i}^{\min} + \varepsilon\% \cdot p_{w_i}^{\min}$, $\overline{p_w}$ represents the probability of the updated UAV returning to each station.
11: The updated probability $\overline{p_w}$ is introduced into the time network model to calculate the maximum time $T\left(\overline{p}_w\right)$.
12: if $T\left(\overline{p}_w\right) > T\left(p_w\right)$ then
13: $p_w = \overline{p}_w, T\left(p_w\right) = T\left(\overline{p}_w\right), N_{ite} = 1$
14: else
15: $N_{ite} = N_{ite} +$
16: end if
17: end while
18: End

3.4 Establishment of Uncertain Time Model

In the delivery process of UAV, the uncertain time model of UAV delivery is established considering the time uncertainty caused by the unsuccessful delivery of UAV and the interference of human and natural conditions in flight, and the intelligent search algorithm is used to solve it.

From the starting point of the UAV distribution task process, the delivery was unsuccessful due to the target customer's failure to receive the package successfully. Although the time consumed by the unsuccessful delivery was consumed, it could not be included in the effective time of the system, which was an unexpected uncertain time. In addition, there were other time uncertainties caused by interference. Due to the existence of uncertainty, the mathematical expectation of constructing the time model is:

$$\min E_t\left(N_D^{w_i}, n_c^{w_i}, n_b^{w_i}, v\right) = \sum_{i=1}^{m}\left(C_d N_D^{w_i} + C_c n_c^{w_i} + C_b n_b^{w_i}\right) + p_e \cdot \left(WD \cdot H \cdot TC \cdot E_o\right)$$
$$s.t.\begin{cases} T \ge T_{\min} \\ m, n, \lambda_j, j = 1, 2, \cdots, n \end{cases} . \quad (3)$$

Where, C_d is the annual cost of each UAV, C_c is the annual cost of each charger, C_b is the annual cost of each battery, p_e is the unit electricity price, WD W is the company's working days per year, H is the company's working hours per day, and E_o is the expected energy consumption of each order delivery task [11].

In this model, the decision variables and objective functions will change according to the different electricity management strategies adopted by the system. In the system with battery exchange strategy, the decision variable will increase the number of batteries to be exchanged. The higher the UAV flight speed set in the system, the better the system time, but also means more energy consumption. Therefore, this paper considers the constraint conditions of establishing cost expectation between the energy consumption per unit distance of UAV flight and flight speed as follows:

$$\sum_{j\in V}\sum_{a\in V}\sum_{z\in Z} C_d C_c C_b \cdot p_e \cdot WD \cdot H + \sum_{j\in V}\sum_{z\in Z}\sum_{r\in Z} c_j^{z\to r} q_{ja} u_j^{j\to w_i} \quad \text{.} \tag{4}$$

$$E_o = E(v)\cdot(ED_w^d + ED_d^w)\,. \tag{5}$$

Where, $u_j^{j\to w_i}$, $j \in V$, $z, r \in Z$ is whether the UAV flies from the charging service point j to the logistics station w_i , if yes, 1 is taken; otherwise, 0 is taken. $t_j^{z\to r}$ indicates the flight time of UAV from station z to station r . The time is calculated according to the schedule. If there is flight, the time is calculated. If there is no flight between stations, the time is not recorded. d_{ja} / δ^z is the route transportation time after taking into account the uncertainty. $t_j^{z\to r} q_{ja}$ The transit time when the transit occurs.

Where, ED_w^d and ED_d^w are the expected distance between the stations, which can be calculated by the approximate mean method. In the annual total cost minimization model of the system, the objective function includes the annual total cost $C_d N_D^{w_i}$ of UAV, the annual total cost $C_c n_c^{w_i}$ of charger and the annual total cost $p_e \cdot (WD \cdot H \cdot TC \cdot E_o)$ of power consumption. In the system using battery replacement strategy, the decision variable also increases the number of batteries to be replaced, so the system cost increases the total annual cost of batteries to be replaced $C_b n_b^{w_i}$. The constraint in the model is that the system time can reach a certain minimum demand level $T_{\min}$. The total number of UAVs needs to be determined in the UAV allocation strategy system. This paper designs a grid search algorithm to analyze the uncertain time model established in this section. The pseudo code of the solution steps is shown in Table 2.

Table 2. Model solving steps

Solution steps
1: Initialization: unit price p_d of the given UAV, unit price p_c of the UAV charger in the warehouse, unit price p_b of the replaced battery, and unit electricity price p_e .
2: Initial solution: enumerate the larger values of all variables to find a feasible solution $\left(N_D^{w_i}, n_c^{w_i}, n_b^{w_i}, v\right)$. For the system under the shared UAV allocation strategy, the heuristic assignment strategy designed in this paper is used to evaluate the system time (Table 1). Calculate the system time T_{CB} , under the initial solution and consider it as the current optimal time.
3: while $T_{CB} > T_{\min}$ do
4: Reduce the number of UAVs by one, i.e. $N_D = N_D - 1$. If the system adopts the shared UAV allocation strategy, it is necessary to optimize the probability of UAV returning to each warehouse through algorithm 1, and then calculate the maximum time T of the system.
5: while $TC \geq TC_{\min}$ do
6: Reduce n_b and n_c , and obtain the optimal flight speed v of UAV under the system structure.
7: Optimize the probability of UAV returning to each station, and calculate the maximum system time T .
8: $T_{CB} = T$
9: end while
10: end while
11: Output: optimal system time T_{CB} , optimal solution $\left(N_D^{w_i}, n_c^{w_i}, n_b^{w_i}, v\right)$.

4 Simulation Experiment and Result Analysis

4.1 Accuracy and Validity of the Model

In this paper, Simulation software Arena is used for simulation [12], and verify the operation results of UAV under the two time models. When using this simulation model to calculate the maximum time of the system, in order to ensure that all UAVs in the system are working, the order arrival rate $\sum_{j=1}^{n}\lambda_{d_j}$ is set to a large value to ensure the utilization rate $\rho_D \geq 99\%$ of UAVs in the system. The schematic diagram of system simulation is shown in Fig. 3, and the basic parameters of the model are shown in Table 3.

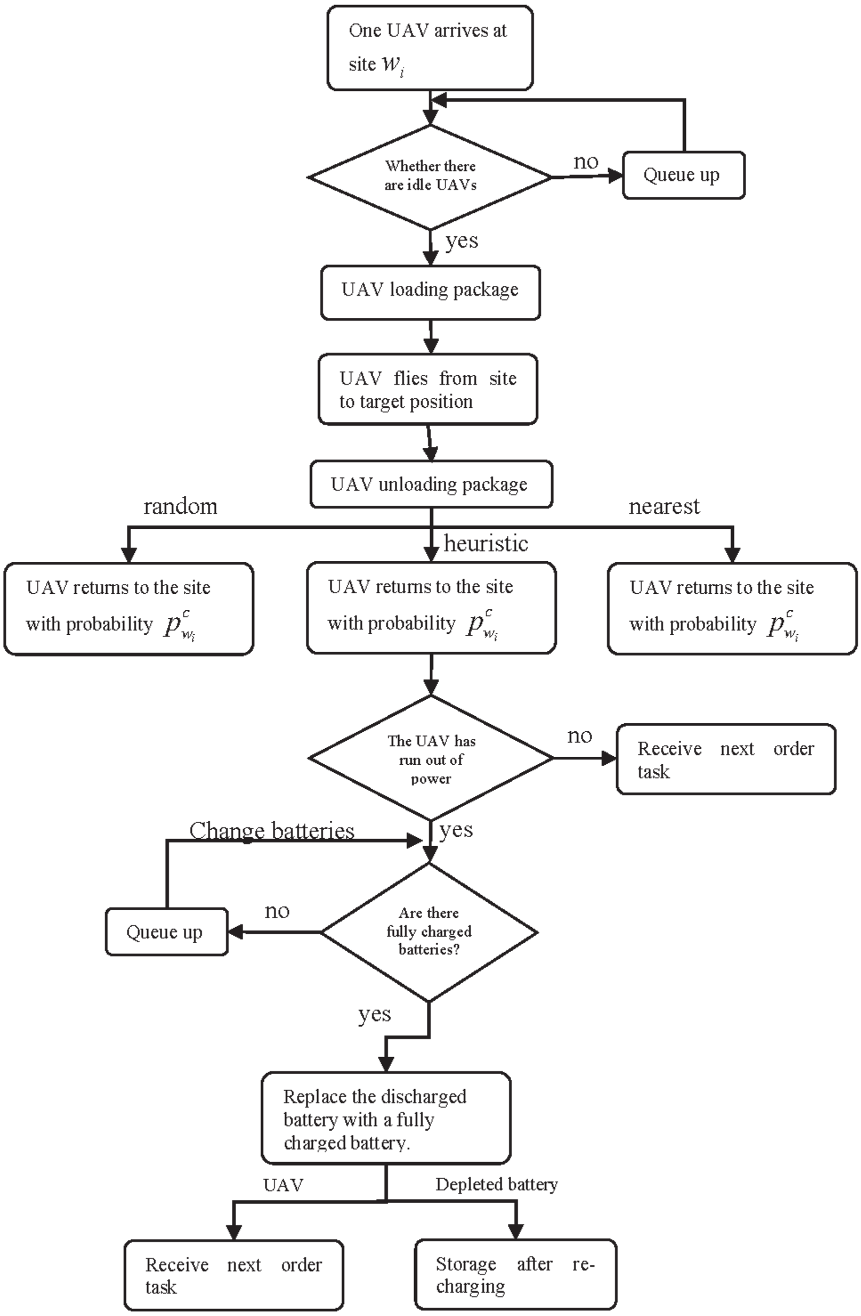


Fig. 3. System simulation flow chart

Table 3. Simulation experiment parameters

$d_{i,j}(m)$	$\lambda_{d_j}(/h)$	$t_{iu}(s)$	N_D	n_c	n_b	$t_c(h)$	$t_s(s)$
U[4000, 8000]	U[1, 10]	130	70	10	10	[1, 2]	300

For each system, this paper first warms up the simulation model by running it for 24 hours, through which the possible initial deviation can be eliminated. Then run for 30 times, each simulation lasts for 240 hours, which can make the half width of the 95% confidence interval of the maximum system time less than 2% of the average value. Finally, the relative error between the system time T_A and the simulation model time T_S is obtained by analyzing the theoretical model through Formula 6.

$$\delta_{TC} = \frac{\left|\overline{T_S} - T_A\right|}{\overline{T_S}} \times 100\% . \tag{6}$$

Where, $\overline{T_s}$ is the average system time obtained after repeatedly running the simulation model. The simulation results are shown in Table 4, which is the average relative error of the system under various conditions.

Table 3 shows the average relative error of the system under different conditions, Fig. 4 shows the frequency of different values of relative error. The results show that the average relative error is 2.87%, and the maximum relative error is not higher than 7%. The error comes from the waiting time of UAV at the station. The results show that the closed queuing network model constructed in this paper can accurately and effectively estimate the maximum time capacity of the system.

Table 4. Simulation experiment results

(m,n)	Time model	Strategies for returning to the logistics site	$T_S(h)$	$T_A(h)$	$\delta_T(\%)$
$(4,80)$	definite	random	276.42	222.73	1.62
	indefinite	designated	217.80	214.33	1.57
$(6,24)$	definite	random	265.93	264.78	0.66
	indefinite	designated	280.98	278.12	1.00
$(4,80)$	definite	random	219.56	211.98	3.29
$(6,24)$	indefinite	designated	207.87	201.84	2.87

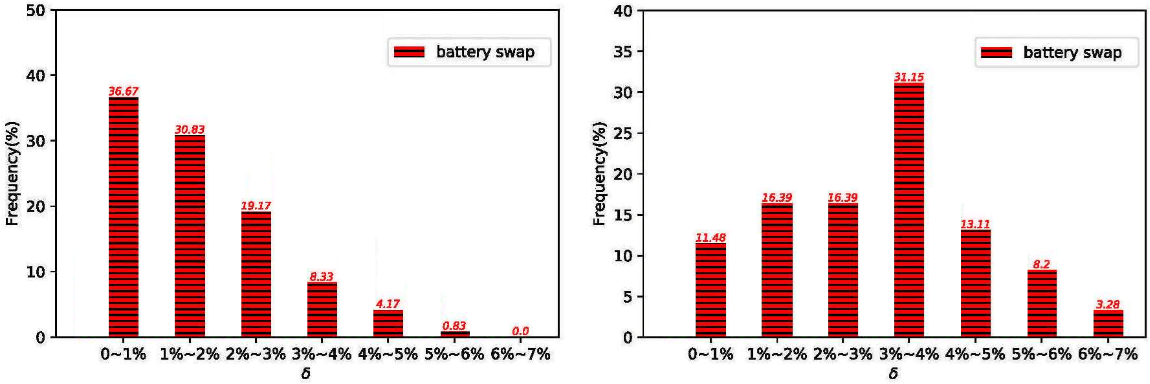
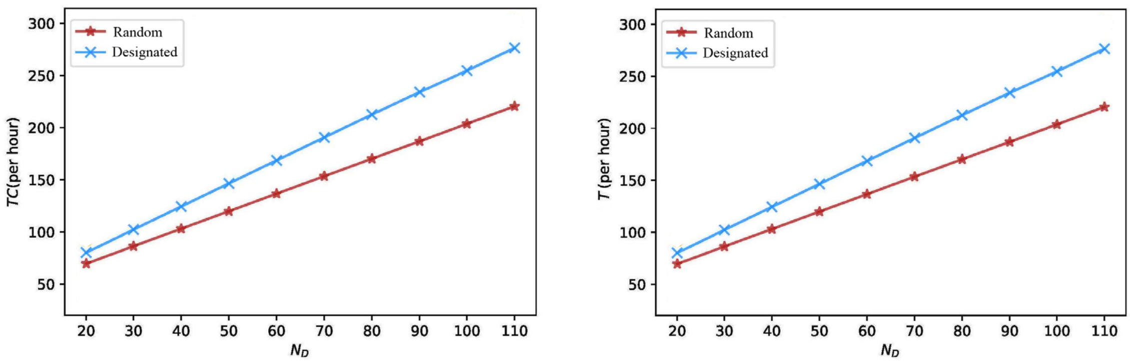


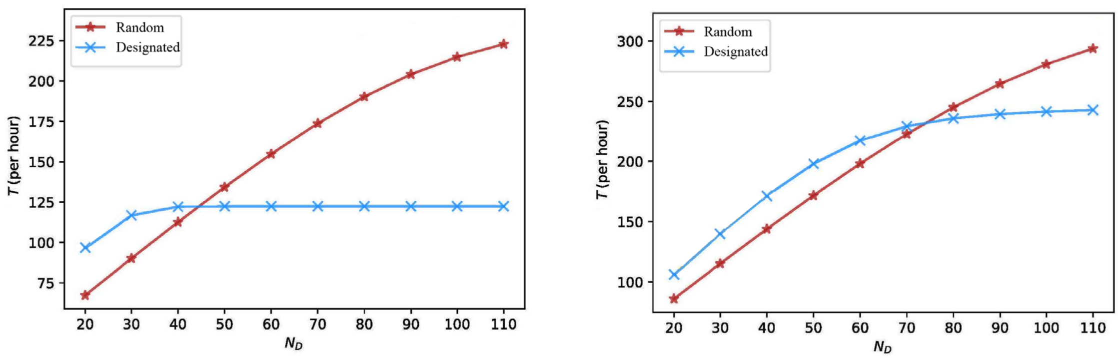
Fig. 4. Frequency of different values of relative error

4.2 Analysis of UAV Return Strategy

This section compares the different scheduling strategies of the UAV returning to the logistics site through numerical experiments. When the UAV returns, there are two solutions: one is to return to the designated site and wait for the next delivery task; The second is to give priority to the logistics station where the first distribution task is located according to the queuing situation of the existing distribution task list of the system, and then carry out distribution. In either case, the analysis is based on the definite time model and the uncertain time model. In this paper, the number of logistics stations is expressed in m ，The number of battery power supply stations is n .we consider two systems: $m = 4$, $n = 80$ and $m = 6$, $n = 24$. Other parameters of the system are the same as those in Table 3. The experimental results are shown in Fig. 5.



(a) $m = 4, n = 80$ definite time model (b) $m = 6, n = 24$ definite time model



(c) $m = 4, n = 80$ indefinite time model (d) $m = 6, n = 24$ indefinite time model

Fig. 5. Analysis of different strategies under different time models

According to the comparison results in Fig. 5, the following conclusions can be drawn:

(1) Under the determined time model, the UAV will fly to the logistics station where the order is placed first at the current time to take the package for the next distribution according to the queuing situation of the system order task. This strategy will take the minimum time for the system.

(2) Under the uncertain time model, there is an intersection between the strategy curve of flying to the station and the strategy curve of flying back to the designated station according to the task order queue. Intersection description: when the number of UAVs is less than the number of intersections, the time spent by UAVs flying to the designated logistics station system is more than the time spent by UAVs queuing up task stations according to orders. Therefore, the number of UAVs is the main reference factor in strategy selection.

5 Conclusion

To sum up, for the timeliness of e-commerce distribution, this paper gives guidance and suggestions for the optimal scheduling strategy of UAV scheduling in the community intelligent logistics system:

(1) The system should make a delivery task list according to the probability of successful delivery. The probability value should be set to a higher value. The distribution target with a higher probability is considered to be successful, while the distribution target with a lower probability will fail.

(2) For target customers with a high delivery success rate, using a designated flight strategy, the UAV time is fixed, the time consumed is linear with the number of UAVs, and the number of UAVs is proportional to the amount of parcel delivery. Therefore, for the target customers that can be delivered successfully through the system judgment, the designated strategy is adopted, and the UAV will return to the designated site regularly.

(3) For customers who may fail to deliver, that is, the uncertain time of delivery, the uncertain factors discussed in the previous chapter have a large proportion of impact on the unsuccessful delivery of UAVs, so the system determines that they are target customers with low delivery probability. As shown in Fig. 5, scheduling strategies are arranged according to the number of UAVs, and the number of UAVs can be calculated by simulation using Arena.

At the end, deterministic and uncertain time models is established, and a heuristic algorithm is designed. The system optimization goal is to minimum time. However, this paper does not discuss the optimization of the location of UAV power supply station. The future research direction is to optimize the whole process of intelligent logistics terminal, aiming to build a more scientific and reasonable scheduling strategy in an all-round way.

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