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RESEARCH ON THE SITE SELECTION AND PATH LAYOUT OF THE LOGISTICS DISTRIBUTION CENTER OF MARINE SHIPS BASED ON A MATHEMATICAL MODEL

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Abstract:

For logistics enterprises, site selection and path layout are related to the cost and efficiency of distribution, which is a very critical issue and has an important impact on the development of enterprises. Compared with land logistics, the cost of marine ship logistics is higher due to the high cost of ships, so the research on the location and path layout of its distribution centers is also particularly important. This paper established a two-layer model under the assumption that unit transportation costs and administration expenses are known for the site selection and path layout problems of marine ship logistics distribution centers. Corresponding constraint conditions were set. The upper layer was the optimization model of the site selection problem of the distribution center, and the objective function was to minimize operating and construction costs and was solved using the quantum particle swarm optimization (QPSO) algorithm. The lower layer was the optimization model of the distribution path layout, and the objective function was to minimize the logistics distribution cost and was solved using the ant colony optimization (ACO) algorithm. The model was verified through an example analysis. It was assumed that there were three ships, five candidate distribution centers, and ten customer points. The model was solved in MATLAB software. The results of the example analysis showed that compared with K-means, genetic algorithm (GA), and particle swarm optimization (PSO)-ACO algorithms, the QPSO-ACO algorithm had the shortest running time, about 60 s, which saved about 50% compared to the K-means algorithm. The optimal cost of the QPSO-ACO algorithm was 293,400 yuan, which was significantly lower than the K-means, GA, and PSO-ACO algorithms (459,600 yuan, 398,300 yuan, and 357,700 yuan). In this example, the site obtained by the QPSO-ACO algorithm was distribution center 2, and the obtained path distribution was 1-7-5-4, 2-6-3, and 10-8-9. The results verify the effectiveness of the QPSO-ACO algorithm in solving the problem of site selection and path layout. The QPSO-ACO algorithm can be applied in the actual marine ship logistics.

Keywords: *mathematical model, distribution center, path layout, ship logistics, optimization algorithm*

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1. Introduction

With the development of the market, logistics enterprises have been developed rapidly. With the improvement of ship performance, maritime logistics has also progressed (Alexahina, 2020), the frequency of logistics distribution through ships has increased, and ship logistics has been more widely studied. For logistics enterprises, the site selection of distribution centers and path layout are always very important issues. Optimizing the location and route layout of distribution centers helps improve distribution efficiency and reduce cost (Droździel et al., 2017), which can improve users' satisfaction and increase enterprises' revenue; therefore, the research on this issue has important practical significance. Site selection and path layout are very common in practical production activities (Drexl and Schneider, 2015), and many methods have been well applied (Drexl and Schneider, 2017). This paper mainly studied the site selection and path layout scheme for marine ship logistics distribution center, established a mathematical model, solved the model by using a heuristic algorithm, and verified the reliability of the proposed method by an example analysis. This work contributes to further optimization and development of marine logistics.

Literature review

Some studies about site selection are as follows. Hao and Wei (2016) studied the site selection problem of hazardous waste, considered the system operation cost and risk level to residents based on multi-objective mixed integer programming, solved the model using Lingo optimization solver, and conducted numerical experiments. Zhang et al. (2021) established an optimization model considering food spoilage, cold storage, and carbon emission factors for the site selection problem of cold chain low-carbon logistics in the Beijing-Tianjin-Hebei region and solved the model using an artificial fish swarm algorithm combined with RNA calculation. They verified the effectiveness of the method through simulation experiments. Sawicki et al. (2021) investigated the problem of siting new tram stops in public transportation systems. They used a multi-criteria decision aid (MCDA) method to recommend new stop locations in the central part of the transportation system network and found that the method was reliable and credible through experiments. Wu et al. (2015) studied a two-level capacity facility siting problem and aimed to minimize the cost under constraints such as warehouse scale and customer source. They solved it with the Lagrange relaxation method and found through numerical experiments that the method was effective. Some studies concerning path layout are shown below. Xiong and Xu (2021) optimized the logistics distribution route with the fish swarm algorithm to determine the shortest route of logistics distribution. They found through experiments that the method jumped out of the locally optimal solution and obtained the shortest route. Hou et al. (2021) studied unmanned logistics distribution. They designed a model for logistics scheduling and distribution considering factors such as vehicle load and time window, solved it with the genetic algorithm (GA) and the simulated annealing algorithm, and verified the effectiveness of the method through case analysis. Koç et al. (2016) studied the fleet size and mixed the location-routing problem with time windows and aimed to minimize vehicle, station, and path costs. They solved the mixed integer programming formula using the hybrid evolutionary search algorithm (HESA) and found that the method was effective through extensive computational experiments. Jin et al. (2021) analyzed the vehicle path problem with fuzzy demand, established a multi-objective planning model with maximum satisfaction and minimum cost objectives, and conducted a simulation analysis with a dairy distribution as an example. They found that the model had good structure and applicability and provided guidance for the actual path layout. Peng et al. (2021) analyzed the path layout of passenger trips in urban transportation networks. They solved the problem with a genetic algorithm (GA) and Monte Carlo simulation by taking travel cost and the number of interchanges as constraints and the shortest total travel time as the objective. An example analysis showed that the method provided satisfactory convergence performance and efficiency. Some studies about the problem of site selection-path combination are as follows. Yang and Sun studied the site-path problem for electric vehicle change stations. After establishing an integer programming model, they solved it using a heuristic algorithm improved by tabu search. They found that the method had a higher search efficiency and thus produced good solutions on instances. Marinakis (2015) proposed a particle swarm optimization algorithm for discrete optimization problems to solve the site-path problem. The example analysis revealed that the method achieved a good solution for problems with stochastic demands. Ghorbani et al. (2016) studied the multi-product and multi-period location-routing-inventory problem, used a hybrid algorithm based on imperialist competitive-simulated annealing (IC-SA) to solve the model, and found through experiments in numerical examples that the IC-SA algorithm was more advantageous in terms of solution quality and CPU time. Schiffer et al. (2017) studied the path of electric vehicles and the site selection of charging stations and aimed at minimizing travel distance, the number of vehicles required, the number of charging stations, and the total cost. They established an objective function and found through experiments that the method achieved better results. Sun et al. (2018) studied the transport cost of parts of scraped cars and developed a two-layer model. The upper layer determined the site of distribution centers, and the lower layer determined the distribution path under any site selection mode. They carried out experiments through actual data to verify the effectiveness of the proposed method.

2. Mathematical modelling of site selection and path layout of logistics distribution centre

Site selection is an activity carried out by enterprises for the purpose of developing markets and improving customer satisfaction. The first situation is to select sites for small facilities by taking products and production methods into account. The second situation is to select sites for factories, warehouses, service centers, and distribution centers of enterprises, which is an important issue in modern logistics (Chi et al., 2019) and is also the subject of this paper.

Good and bad site selection has a direct impact on the development of enterprises and is closely related to the costs and profits of enterprises. Site selection needs to meet the long-term development needs of enterprises, i.e., maximizing returns with minimal investment. For logistics enterprises, a distribution center refers to the place for an integrated logistics distribution business, with a sound distribution function and small radiation range, and its main function is to distribute goods. The distribution center is a transfer node that can receive supplies from suppliers and distribute goods to customers in time.

Different layouts may lead to great differences in cost and efficiency of the whole marine ship logistics system. Therefore, the site selection of the distribution center and path layout are important parts of enterprise construction, which should realize the maximum utilization of equipment and personnel, simplify the operation process, and reduce the distribution cost through reasonable arrangement and distribution to achieve the maximum benefit of enterprises.

Compared with land logistics distribution, the most prominent feature of maritime logistics distribution is the high cost of ships. The manufacturing and production of ships are complex and require very high technologies; therefore, the shipbuilding cost is also very high. The shipbuilding industry and the development of marine logistics are closely related, and the high cost of shipbuilding also increases the cost of maritime logistics distribution. Therefore, controlling logistics costs has a very important role in developing marine logistics.

For the problem of site selection and path layout of the marine ship logistics distribution center, the purpose is to make the cost of construction, operation, and distribution the lowest. In order to establish the mathematical model, it is first necessary to make the hypothesis that:

(1) distribution centers are selected from known alternative areas;
(2) the unit transportation cost is known;
(3) the unit administration expense is known;
(4) the ship transport speed is known and fixed;
(5) the vessel model numbers are all the same;
(6) every customer can only accept the service of one ship;
(7) ships incur penalty costs if they fail to deliver goods to customers within the desired time.

The required parameters of the model and their meanings are shown in Table 1.

According to Table 1, a mathematical model of the site selection and path layout problem of the marine ship logistics distribution center was established, and the site selection problem was used as the upper model to minimize the construction and operation costs, written as:

$$minL = \sum_{r \in G} F_r Z_r + \sum_{r \in G} A_r \mathrm{Z_r}. \tag{1}$$

The constraints of the upper model are as follows.

(1) At least one distribution center needs to be established:

$$\sum_{r \in G} Z_r \geq 1. \tag{2}$$

(2) The carrying capacity of the distribution center needs to be greater than the customer's demand:

$$\sum_{r\in G} Q_r Z_r \geq \sum_{j\in H} q_j. \quad (3)$$

(3) Construction costs cannot exceed the budget:

$$\sum_{r\in G} F_r Z_r \leq CFtotal. \quad (4)$$

(4) Operating costs cannot exceed the budget:

$$\sum_{r\in G} A_r Z_r \leq CAtotal. \quad (5)$$

(5) The distribution capacity of every ship must not exceed the maximum carrying capacity of the ship:

$$q_j \leq q_{max}. \quad (6)$$

The path layout problem is the lower model with the objective of minimizing the distribution cost, written as:

$$minZ = \sum_{i\in S}\sum_{j\in H}\sum_{k\in V} C_{ij} X_{ijk} D_{ij} + \\ + \sum_{k\in V} C_k X_k + \sum_{j\in H}(1-R_j) p_i(s_i), \quad (7)$$

$$p_i(s_i) = \begin{cases} c_1(E_i - s_i), s_i < E_i \\ 0, E_i < s_i < L_i \\ c_2(s_i - L_i), s_i \geq L_i \end{cases}, \quad (8)$$

$$p_i(s_i) = c_1 max((E_i - s_i), 0) + \\ + c_2 max\big((s_i - L_i), 0\big). \quad (9)$$

The constraints of the lower model are:

(1) every customer can only accept one ship for delivery:

$$\sum_{k\in V}\sum_{j\in H} C_{ij} X_{ijk} = 1, j \in H; \quad (10)$$

(2) the distribution volume of every route should not exceed the carrying capacity of every ship:

$$\sum_{j\in H}\sum_{i\in S} q_{ij} X_{ijk} \leq Q_k, k \in V; \quad (11)$$

(3) every ship belongs to only one distribution center:

$$\sum_{r\in G}\sum_{j\in H} X_{rjk} \leq 1, k \in V. \quad (12)$$

Table 1 Parameters needed to build the mathematical model and their meanings

Parameters	Meaning
$G = \{r \mid r = 1,2,\cdots,r\}$	Alternative distribution center
$H = \{i \mid i = 1,2,\cdots,n\}$	Customer node
F_r	Cost of building a distribution center at r
A_r	Cost of operating a distribution center at r
C_{ij}	The unit transport cost from customer point i to customer point j
D_{ij}	The distance from customer point i to customer point j
C_k	The fixed usage and maintenance costs of ship k
Q_k	The carrying capacity of ship k
u	The average speed of the ship
Q_r	The carrying capacity of distribution center r
q_j	The average demand of customer point j
E_j	The penalty cost of customer point j
Z_r	If a distribution center is built at r, $Z_r = 1$; otherwise, $Z_r = 0$.
R_j	If client j's time window is satisfied, then $R_j = 1$, and vice versa k = 0.
X_k	If ship k is used, then $X_k = 1$, and vice versa $X_k = 0$.
X_{ijk}	If ship k delivers cargo from distribution center r to customer point j, then $X_{ijk} = 1$, and vice versa $X_{ijk} = 0$.
Y_{ij}	If the cargo of customer point j is delivered from distribution center r, then $Y_{ij} = 1$ and vice versa, $Y_{ij} = 0$.
$[E_i, L_i]$	Optimal service time window
$p_i(s_i)$	Penalty cost function
s_i	Arrival time of ship arrival at customer point i
c_1	Waiting cost per unit time for ships that arrived early
c_2	Penalty cost per unit time for ships that arrived late

3. A method for solving the mathematical model

The mathematical model of the site selection and path layout of the logistics distribution center is an NP-hard problem involving a large amount of data, and it is difficult to get the optimal solution by the traditional exact algorithm; therefore, this paper used a heuristic algorithm to solve the established two-layer model.

First, the upper model was solved using the particle swarm optimization (PSO) algorithm (Kartono et al., 2021). The PSO algorithm was combined with the quantum evolutionary algorithm (Moriyama et al., 2015) to obtain the quantum particle swarm algorithm (QPSO) in order to improve its defects, such as premature convergence. Quantum encoding was performed on the particles, and the current position of the particles was represented as:

$$p_i = \begin{bmatrix} \cos\theta_{i1} & \cos\theta_{i2} & \cdots & \cos\theta_{iD} \\ \sin\theta_{i1} & \sin\theta_{i2} & \cdots & \sin\theta_{iD} \end{bmatrix}. \tag{13}$$

In the population, every particle traverses two positions in the D space:

$$p_i^{|0\rangle} = [\cos\theta_{i1}, \cos\theta_{i2}, \cdots, \cos\theta_{iD}], \tag{14}$$

$$p_i^{|1\rangle} = [\sin\theta_{i1}, \sin\theta_{i2}, \cdots, \sin\theta_{iD}], \tag{15}$$

where $|0\rangle$ and $|1\rangle$ are the quantum bits.

The j-th quantum-bit was written as $\left[\alpha_{ij}, \beta_{ij}\right]^T$. α and β were the quantum probability amplitudes, $|\alpha|^2 + |\beta|^2 = 1$. If the upper and lower limits of the search range of particle i were b_i and a_i, respectively, then the solution space variation was written as:

$$x_{ij}^{|0\rangle} = a_i + \alpha_{ij}(b_i - a_i), \tag{16}$$

$$x_{ij}^{|1\rangle} = a_i + \beta_{ij}(b_i - a_i) \tag{17}$$

In QPSO, if the optimal historical phase mass of particle i at the j-th dimension in the previous k iterations was θ_{hij}^k, and the globally optimal phase mass was θ_{gj}^k, the update formula of the quantum particle swarm was written as:

$$\Delta\theta_{ij}^{k+1} = g\Delta\theta_{ij}^k + c_1 r_1^k\left(\theta_{hij}^k - \theta_{ij}^k\right) + \\ + c_2 r_2^k\left(\theta_{gj}^k - \theta_{ij}^k\right), \tag{18}$$

$$\begin{bmatrix} \cos\theta_{ij}^{k+1} \\ \sin\theta_{ij}^{k+1} \end{bmatrix} = \begin{bmatrix} \cos\left(\theta_{ij}^k + \theta_{ij}^{k+1}\right) \\ \sin\left(\theta_{ij}^k + \theta_{ij}^{k+1}\right) \end{bmatrix} \tag{19}$$

where $\Delta\theta_{ij}^{k+1}$ is the particle phase shift, g is the inertia factor, c_1 and c_2 are the learning factors, and $\cos\theta_{ij}^{k+1}$ and $\sin\theta_{ij}^{k+1}$ are the probability amplitudes.

The QPSO algorithm was applied to the solution of the upper model. The distribution center points to be selected were initialized. The particle coordinates were encoded, followed by solution space variation. Customer points were allocated to the nearest distribution center according to the location of the particles.

The cost of site selection cost was taken as the fitness function to calculate the individual historical optimum and the global optimum. The particle state was updated through continuous iterations until the maximum iteration number of iterations was reached. Finally, the optimal solution was output.

Then, the lower model was solved using the ant colony algorithm (ACO) (Ikhlef et al., 2021). The ships are coded according to the order in which they travel, and assuming that the ships start from distribution center 1 and deliver to customer points in the order of 9-5-6-4, the coding of the path was written as 1-9-5-6-4-1. The probability of an ant reaching every customer point was written as:

$$p_{ij} = \frac{\tau_{ij}^\alpha \cdot \eta_{ij}^\beta}{\sum_{h \notin tabu}\left(\tau_{ih}^\alpha \cdot \eta_{ih}^\beta\right)}, \tag{20}$$

where τ_{ij} is the pheromone content on path ij, η_{ij} is the expected value, $tabu$ is the set of infeasible nodes, and α and β are the heuristic factors. According to the roulette algorithm, the next customer point was selected. Considering the constraints of the model, if the conditions were satisfied, the customer point was added to the path. In addition, the path was randomly selected according to crossover probability p_m to avoid the algorithm from falling into local convergence. At the end of every cycle, the pheromone content was updated, and the formula was written as:

$$\tau^{new} = \rho \times \tau^{old} + \sum_{k=1}^{K} \Delta\tau_{ij}^k, \tag{21}$$

$$\Delta\tau_{ij}^{k}=\begin{cases}\frac{S}{\sum D_m}\times\frac{D_{ij}}{D_m}, \text{ant } k \text{ passes path } ij\\ 0, \text{ant } k \text{ does not pass path } ij\end{cases}, \qquad (22)$$

where τ^{new} and τ^{old} are the content of new and old pheromones, ρ refers to the degree of pheromone retention, $\Delta\tau_{ij}^{k}$ is the pheromone increment of ant k on path ij, S is the total amount of pheromone released by the ant, D_{ij} is the distance from customer point i to j, and D_m is the total travel distance of all ships starting from distribution center m.

4. Experimental analysis

In order to verify the validity of the model, the model was analyzed by a calculating example. It was assumed that there were five ships, five alternative distribution centers, and ten customer points. The locations of the distribution centers and customer points are shown in Figure 1, and the specific information is shown in Tables 2 and 3. The parameters involved in the construction of the mathematical model are shown in Table 4. The parameters involved in the solution of the model are shown in Table 5.

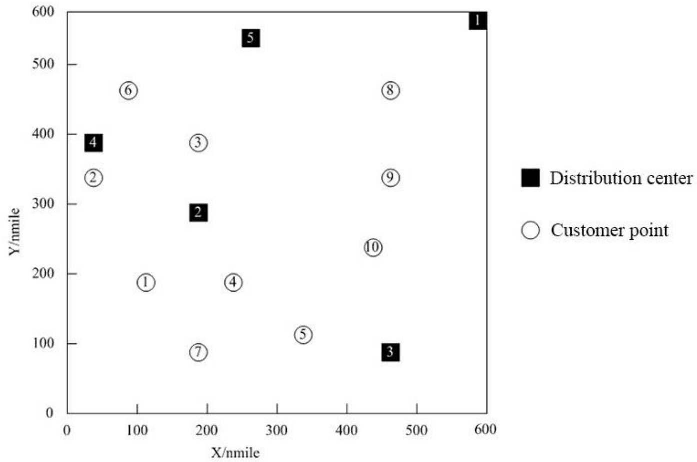

Fig. 1.Locations of alternative distribution centers and customer points

Table 2. Information on alternative distribution centers

Alternative distribution center	**Construction cost /ten thousand yuan**	**Operating costs /ten thousand yuan**	**Carrying capacity /ton**
1	15	5	15
2	20	6	20
3	25	7	20
4	25	7	18
5	30	8	22

Table 3. Information of customer points to be delivered

Customer points to be delivered	**Time window**	**Demand/ton**	**Service time/min**
1	[9:30,12:00]	0.3	20
2	[9:30,11:00]	0.4	25
3	[8:30,10:00]	0.3	20
4	[9:30,10:00]	0.5	30
5	[9:00,11:00]	0.3	20
6	[10:30,12:00]	0.5	30
7	[9:00,10:00]	0.6	35
8	[8:30,9:00]	0.3	20
9	[10:30,11:00]	0.2	15
10	[9:30,11:00]	0.5	30

Table 4. Mathematical model parameter settings

Parameters	Numerical value
Ship capacity	10 t
Average speed of ships	60 km/h
Unit transportation cost	500 RMB/nmile
Ship unit usage cost	1500 RMB/ship
Unit waiting cost	50 RMB/hour
Late cost per unit	100 RMB/hour
Construction cost budget	400,000 yuan
Running cost budget	100,000 yuan

Table 5. Mathematical model parameter settings

Parameters	Numerical value
The QPSO algorithm	
Maximum number of iterations	100
Inertia factor	[0.5,0.8]
Learning factor	2.1
The ACO algorithm	
Population size	100
Maximum number of iterations	150
Degree of pheromone retention	0.95
Total amount of pheromones	1500
Heuristic factors	$\alpha = 1, \beta = 3$
Crossover probability	0.01

The mathematical model was solved in MATLAB software. The QPSO-ACO method was compared with other methods. The steps of the four methods are as follows.

(1) The K-means algorithm [23]-based method: The upper and lower models were solved by the K-means algorithm to obtain the optimal distribution center and path. The total cost was calculated.
(2) The GA-based method [24]: The upper and lower models were solved by GA to obtain the optimal distribution center and optimal path. The total cost was calculated.
(3) The PSO-ACO method: The upper model was solved by PSO, and the lower model was solved by ACO to obtain the optimal distribution center and optimal path. The total cost was calculated.
(4) The QPSO-ACO method: The upper model was solved by QPSO, and the lower model was solved by ACO to obtain the optimal distribution center and optimal path. The total cost was calculated.

After the distribution center siting result and path layout result of the four algorithms, their solution time and optimal total cost were compared.

First, a comparison of the different algorithms in terms of the running time for the solution is shown in Figure 2.

It was seen from Figure 2 that among the four algorithms, the K-means algorithm took the longest running time, more than 100 s, to solve the site selection and path layout models, and the time consumed by the GA was between 80 s and 90 s, which was slightly shorter than the K-means algorithm. The running time was significantly reduced when the hybrid algorithm solved the two-layer model. The running time required for the PSO-ACO algorithm was 70 s - 80 s, which saved 40 s - 50 s compared to the K-means algorithm and about 10 s compared to the GA. Finally, after the improvement of the PSO algorithm using quantum evolution, the running time of the QPSO-ACO algorithm was around 60 s, which saved about 50% compared to the K-means algorithm. These results verified the efficiency of the QPSO-ACO algorithm for solving the mathematical model.

The optimal costs of the site selection and path layout schemes obtained by different algorithms were compared, and the results are shown in Figure 3.

It was seen from Figure 3 that in the site selection and path layout problem, the optimal cost of the schemes obtained by the K-means algorithm, GA, and PSO-ACO algorithm was 459,600 yuan, 398,300 yuan, and 357,700 yuan, and the optimal cost of the schemes obtained by the PSO-ACO algorithm was 357,700 yuan, which was 22.17% less than the K-means algorithm and 10.19% less than the GA. These results indicated that the hybrid algorithm obtained better schemes. The optimal cost of the schemes obtained by the QPSO-ACO algorithm was 293,400 yuan, which was 36.16% less than the K-means algorithm, 26.34% less than the GA, and 17.98% less than the PSO-ACO algorithm. These results suggested that the QPSO-ACO algorithm had high calculation efficiency and higher solution quality and spent the lowest costs on site selection and path layout.

The optimal site selection and path layout schemes obtained by the four algorithms are shown in Figures 4-7 and Table 6.

As shown in Figures 4-7 and Table 6, the site selection result of the distribution center obtained by different algorithms was different. The optimal distribution center obtained by the K-means algorithm was 4, the result of the GA was 3, and the result of

PSO-ACO and QPSO-ACO algorithms was distribution center 2. In terms of the cost, the poor siting performance of the K-means algorithm and GA led to high costs, while PSO-ACO and QPSO-ACO algorithms output more reasonable results for siting. In terms of the path layout, the scheme obtained by the QPSO-ACO algorithm was more reasonable. The distribution path was 1-7-5-4 for no. 1 ship, 2-6-3 for no. 2 ship, and 10-8-9 for no. 3 ship. The final cost of this site selection and path layout scheme was 293,400 yuan.

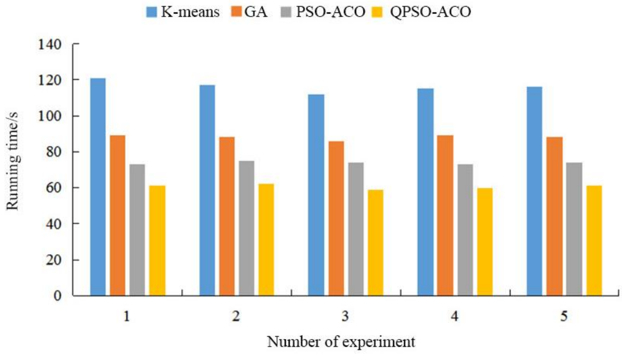

Fig. 2. Comparison of running time between different algorithms

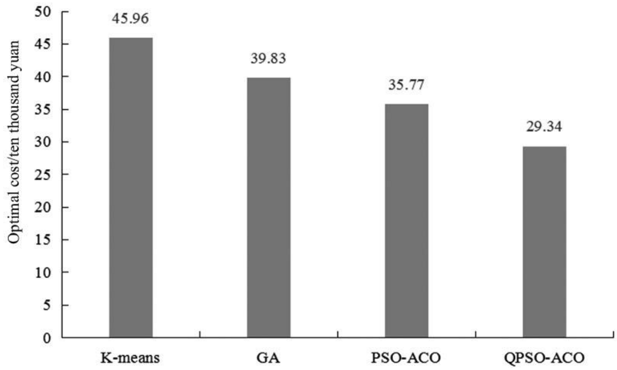

Fig. 3. Comparison of optimal costs between different algorithms

Table 6. Optimal schemes of site selection and path layout

Method	Distribution center	Ship number	Path layout
The K-means algorithm	4	1	6-8
		2	2-1-7-5-4
		3	3-9-10
The GA	3	1	5-4-1-7
		2	2-6-3
		3	10-8-9
The PSO-ACO algorithm	2	1	6-8-3
		2	9-10
		3	2-1-7-5-4
The QPSO-ACO algorithm	2	1	1-7-5-4
		2	2-6-3
		3	10-8-9

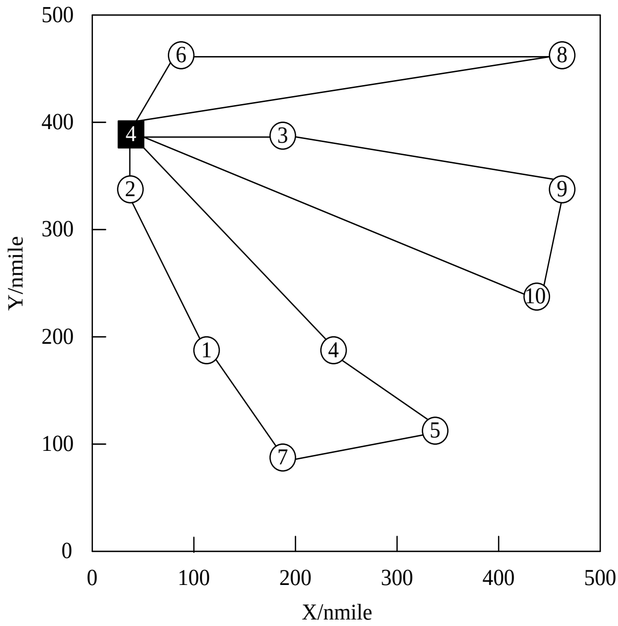

Fig. 4. The path layout scheme obtained by the K-means method

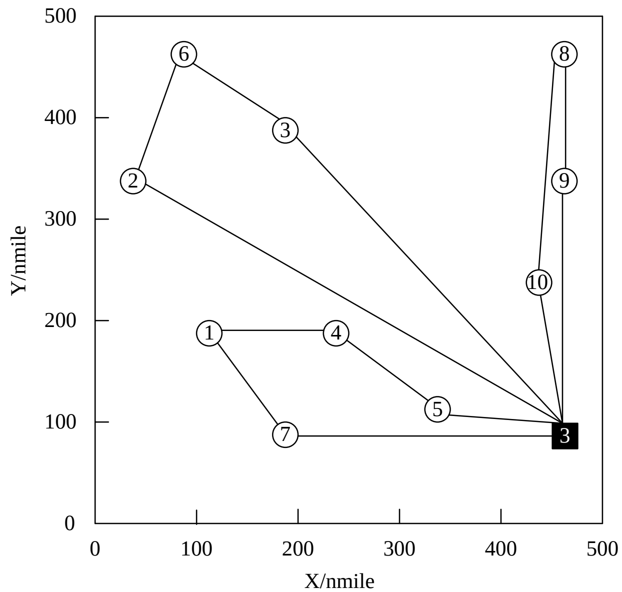

Fig. 5. The path layout scheme obtained by the GA

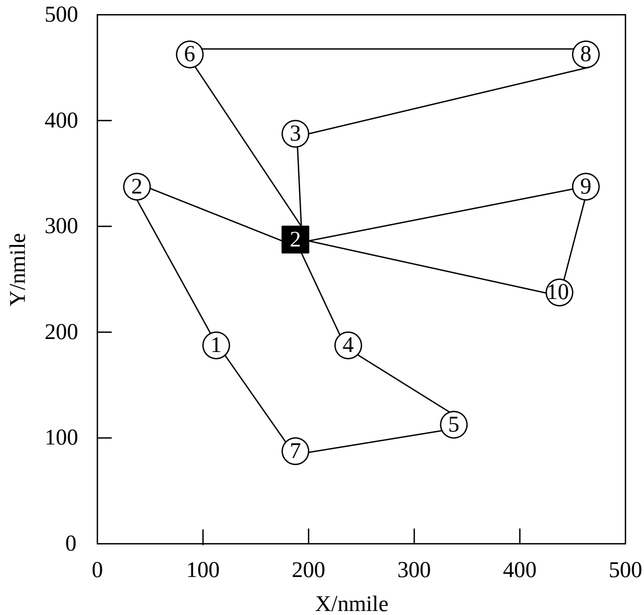

Fig. 6. The path layout scheme obtained by the PSO-ACO method

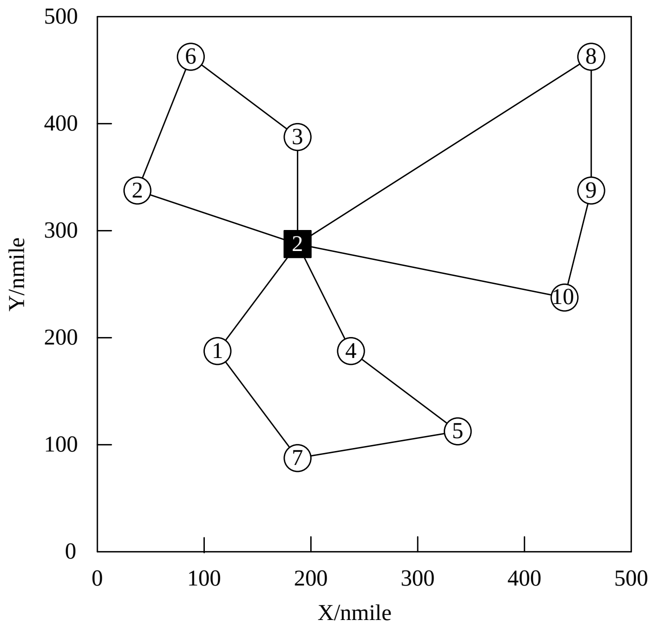

Fig. 7. The path layout scheme obtained by the QPSO-ACO method

5. Conclusions

This paper mainly studied the site selection and path layout of marine ship logistics distribution center, established a two-layer model, solved the model with the QPSO algorithm and ACO algorithm by taking the minimal cost as the objective, respectively, carried out an analysis on a calculating example, and compared the QPSO-ACO algorithm with other methods. The results showed that:

(1) the QPSO-ACO algorithm had the shortest running time, around 60 s, which was 50% shorter than the K-means algorithm;

(2) the optimal cost obtained by K-means, GA, PSO-ACO, and QQPSO-ACO algorithms was 459,600 yuan, 398,300 yuan, 357,700 yuan, and 293,400 yuan, respectively, i.e., the QPSO-ACO algorithm obtained the lowest optimal cost;

(3) in the calculating example, the site selected by the QPSO-ACO algorithm was distribution center 2, and the path layout of the ships was 1-7-5-4, 2-6-3, and 10-8-9.

The results showed that the designed mathematical model and the QPSO-ACO algorithm had high computation efficiency and obtained good results, showing good performance. They realized the optimization of the site selection of distribution center and path layout, which can be further promoted and applied in practice to motivate the further development of shipping logistics

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