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Emergency Routing and Structural Optimization of E-commerce Logistics Network for Parcel Transportation Based on Multiple Models

Zhe Guo*, #, Tong Jing#, Haichao Zhu#, Xuejiayi Xu#

Department of Computer Engineering, Qingdao City University, Qingdao, 266106, China
**Corresponding author: guozhe202307@163.com*
#These authors contributed equally.

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Abstract: The adjustment measures include closing or opening new routes, but not adding new logistics sites. To achieve dynamic adjustment of the logistics network's route structure, including the closure or development of new routes, the aim is to minimize the number of routes affected by changes in cargo volume before and after the closure of DC9, while maintaining a balanced workload among the routes. Therefore, an Ant Colony Optimization (ACO) algorithm model is established, and MATLAB and SPSSPRO are utilized to solve the prepared table based on the ACO model. The obtained routes DC69→DC5, DC69→DC8, DC69→DC14, and DC69→DC62 have a cargo conformity rate of 97%, with an average route workload of around 7%. The remaining cargo across all routes is 11,280.7. This indicates that the overall results remain unaffected after deleting DC9 and adding the new route DC3→DC1, with no routes exceeding the required conformity, satisfying the practical requirements. Next, an evaluation is conducted to assess the importance of different logistics sites and routes within the network. Taking into account basic conditions, such as parcel quantities, transport frequencies, maximum transport capacities, transfer capacities, and other influencing factors, a TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) analysis model is constructed. The processed table is used to analyze the network's robustness, determining appropriate settings for processing and transport capacities. The objective is to reduce the overall operating costs of the network while ensuring a more balanced distribution of network workload.

1. Introduction

The emergency transportation and structural optimization of e-commerce logistics network primarily involve the issues of emergency transportation and structural optimization of packages within the network [1]. Due to significant fluctuations in e-commerce order volumes and the impact of unforeseen events, the quantity of packages at logistics sites and along routes can vary. Therefore, it is necessary to predict the package quantities at each logistics site and along each route in order to arrange transportation, sorting, and other plans in advance, reducing operational costs and improving operational efficiency [2]. When certain logistics sites are temporarily or permanently unavailable, it is essential to design logistics network adjustment plans to minimize the impact on the network and ensure its normal operation. The logistics network consists of 81 logistics sites and 1049 routes. Assuming that the processing capacity of each logistics site and the transportation capacity of each route are limited by their respective historical maximum cargo volumes [3].

2. The basic funamental of models

2.1 Linear programming model preparation

We utilize a linear programming model for the process. Let's start by establishing the objective function and constraints for the problem [4].

(1) Line capacity limit:

$$\min \sum_{i=1}^{m} \left| x_i - x_{i0} \right| \tag{1}$$

(2) The upper limit of the processing capacity of each logistics site and the upper limit of the transportation capacity of each line cannot exceed the maximum historical cargo volume:

$$(1-n)x_{DC5} + x_i \le d_i \tag{2}$$

(3) Ensure that the cargo volume of DC5-related lines is fully allocated to other lines, and the inbound and outbound cargo volume of each logistics site is balanced, and all are:

$$(1-n) \times x_{DC5} + x_i \tag{3}$$

(4) Ensuring smooth flow of all goods, i.e., ensuring that the outgoing quantity from each logistics site equals the incoming quantity in the daily goods flow network:

$$\sum_{i=1}^{m} x_i = \sum_{i=1}^{m} x_{i0} \tag{4}$$

(5) The cumulative daily total of parcels that failed to circulate normally during the period from January 1 to January 31, 2023 is as small as possible [5]. At the same time, if the quantity of goods delivered on a certain day is greater than the maximum capacity of the line, the excess goods are considered as Goods that are not in normal circulation will be included in the total amount of packages that are not in normal circulation.

Assuming that there are s dates and p venues in the distribution route, construct a forward matrix:

$$Y = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} & \cdots & x_{1p-2} & x_{1p-1} & x_{1p} \\ \hdashline x_{21} & x_{22} & x_{23} & x_{24} & x_{25} & \cdots & x_{2p-2} & x_{2p-1} & x_{2p} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} & \cdots & x_{3p-2} & x_{3p-1} & x_{3p} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} & \cdots & x_{4p-2} & x_{4p-1} & x_{4p} \\ x_{51} & x_{52} & x_{53} & x_{54} & x_{55} & \cdots & x_{5p-2} & x_{5p-1} & x_{5p} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{s-21} & x_{s-22} & x_{s-23} & x_{s-24} & x_{s-25} & \cdots & x_{s-2p-2} & x_{s-2p-1} & x_{s-2p} \\ x_{s-11} & x_{s-12} & x_{s-13} & x_{s-14} & x_{s-15} & \cdots & x_{s-1p-2} & x_{s-1p-1} & x_{s-1p} \\ x_{s1} & x_{s2} & x_{s3} & x_{s4} & x_{s5} & \cdots & x_{sp-2} & x_{sp-1} & x_{sp} \end{bmatrix} \tag{5}$$

Standardize the matrix and record it as Z, each element in Z can be expressed as:

$$Z_{sp} = \frac{x_{sp}}{\sqrt{\sum_{i=1}^{m} x_{sp}{}^2}} \tag{6}$$

The required models are summarized as follows:

$$\min \sum_{s=1}^{m}\sum_{p=1}^{m}\left|x_{sp}^{before} - x_{sp}^{final}\right| \tag{7}$$

$$s.t = \begin{cases} 0 \le \sum_{s=1}^{m}\sum_{p=1}^{m} x_{sp}^{final} \le d_{sp} \\ \sum_{t=1}^{r}\sum_{s=1}^{m}\sum_{p=1}^{m} x_{sp}^{final}(t) \le \sum_{t=1}^{r}\sum_{s=1}^{m}\sum_{p=1}^{m} d_{sp}(t), t = 1,2,\ldots,m \\ \sum_{s=1}^{m}\sum_{p=1}^{m} x_{sp}^{before} = \sum_{s=1}^{m}\sum_{p=1}^{m} x_{sp}^{final} \\ (1-n)x_{DC5} + x_{sp} \le d_{sp} \\ \max_{i=1,2,\ldots,m}\left(x_{sp}^{final} - \frac{\sum_{s=1}^{m}\sum_{p=1}^{m} x_{sp}^{final}}{n}\right) - \min_{i=1,2,\ldots,m}\left(x_{sp}^{final} - \frac{\sum_{s=1}^{m}\sum_{p=1}^{m} x_{sp}^{final}}{n}\right) \le \sigma \\ x_{sp}^{final} \in Z \end{cases} \tag{8}$$

2.2 Establish ACO Ant Colony Algorithm Model

2.2.1 Model Analysis of ACO Ant Colony Algorithm

Ant Colony Algorithm is a heuristic optimization algorithm that simulates the foraging behavior of ants in nature. Functions for finding optimal solutions in a search space. Here, we apply the ant colony algorithm to the route adjustment problem. The goal is to make all parcels flow as normal as possible, and make the number of lines whose cargo volume changes before and after DC9 shut down as small as possible, and keep the workload of each line as small as possible. Possibly balanced [6].

We transform the route adjustment problem into a discrete optimization problem, that is, there are only two cases of the open or closed state of each route, which can be represented by 0 or 1. In order to convert the problem into a form that can be solved by the ant colony algorithm, we need to define the objective function and constraints [7].

(1) The overall framework of ACO:

According to the Figure 1 of the linear programming model in the question, the model is extended to consider the specific opening and closing of DC9 related lines every day. During the activity, we use the carrot group algorithm model (ACO) and use SPSS and matlab to analyze mathematically tool for activities.

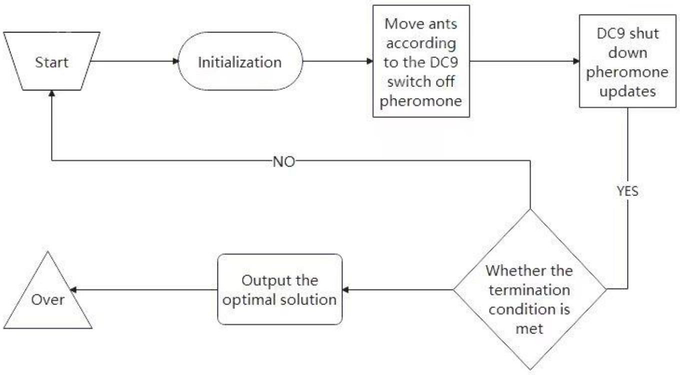

Figure 1: ACO algorithm model flow chart

2.2.2 ACO Model Workstation

We solve it through the matlab program: this function accepts some input parameters, including decision variable matrix x, pheromone importance factor alpha and heuristic information importance factor beta, pheromone matrix tau, heuristic function matrix eta, pheromone increment coefficient Q, the current number of days t, the cargo demand matrix I, the cost matrix c, and the upper limit of transportation capacity fmax [8].

In this function, we first consider allocating the volume of the closed DC9-related route to other routes, and then calculate the transportation volume and cost of each route. Finally, we sum the costs of all routes to get the objective function value.

2.3 Topsis model building

The Importance Evaluation Model of Different Logistics Sites and Routes Based on Topsis TOPSIS is a commonly used comprehensive evaluation method in the group, which can make full use of the information of the original data, and the results can accurately reflect the differences between the eval uation schemes. This paper evaluates the climate data and solves the change of the comprehensive score under the influence of GDP and GGDP [9]. The Topsis algorithm is an algorithm based on the entropy weight method. When dealing with weights, we use the entropy weight method. $W = (\omega_i)_{1\times m}$, The specific results are shown in Table 2 and Table 3:

2.4 The relationship between DC5 and the volume and workload of the rest of the routes

We import the data listed separately into SPSS to get the analysis table:

Table 1: Volume relationship between DC5 and other routes

Logistics route	Volume (pieces)	Workload(%)	Logistics route	Workload(%)	Logistics route	Volume (pieces)	Workload(%)	
DC1-DC2	145	97.98	DC3-DC5	96.79	DC5-DC6	132	92.68	
DC1-DC6	231	96.44	DC3-DC8	98.15	DC5-DC7	85	82.78	
DC2-DC3	181	97.72	DC3-DC9	95.56	DC5-DC9	71	66.80	
DC2-DC4	182	96.69	DC4-DC5	97.04	DC6-DC7	193	97.04	
DC2-DC5	193	94.84	DC4-DC6	78.09	DC6-DC9	170	96.21	
DC2-DC6	146	96.51	DC4-DC7	98.32	DC7-DC8	141	97.55	
DC3-DC4	197	97.53	DC4-DC8	96.06	DC8-DC9	215	98.11	

By including Table 1 and optimizing the objective function using linear programming techniques, you can determine the volume relationship between DC5 and other routes that achieves the desired optimization goal. The specific formulation of the volume relationship and the linear programming model may vary depending on the details and requirements of your specific scenario.

Table 2: Entropy weight method to calculate the weight corresponding to the route index

	information entropy value e	information utility value d	Weights
Package Shipping Quantity	0.673	0.327	34.504%
Package Shipments	index	0.114	12.067%
Maximum Package Shipping Volume	0.675	0.235	24.874%
Balance of parcel transportation	0.732	0.273	28.556%

Table 3: Entropy weight method to calculate the weight corresponding to the site index

index	information entropy value e	information utility value d	Weights
The total amount of goods sent	0.698	0.302	14.441
The total amount of goods received	0.459	0.541	25.872
The number of transmissions	0.874	0.126	6.021
Accepted times	0.562	0.438	20.932

Based on the weights obtained using the entropy weighting method in Table 2 and Table 3, we can make the following summary: For the route indicators (Table 2), the package transportation quantity has the highest weight of 34.504%. The next important indicator is the package transportation balance with a weight of 28.556%. The maximum package transportation volume has a weight of 24.874%, while the package transportation frequency has the lowest weight of 12.067%. For the site indicators (Table 3), the weight for the total received goods volume is the highest at 25.872%. The next significant indicator is the number of goods received with a weight of 20.932%. The weight for the total goods sent is 14.441%, while the weight for the number of times goods are sent is the lowest at 6.021%.

In conclusion, in terms of route indicators, the package transportation quantity and package transportation balance are the most important factors in evaluating the routes. Regarding site indicators, the total received goods volume and the number of goods received hold higher importance. These weightings provide guidance for decision-makers to balance and optimize various indicators when making decisions.

3. Results

3.1 The establishment of simulation model

We import the data table DC5.xlsx listed separately into SPSSPRO to get the analysis table:

Get the relationship between DC5 and other lines and their frequencies. As shown in Figure 2 below**:**

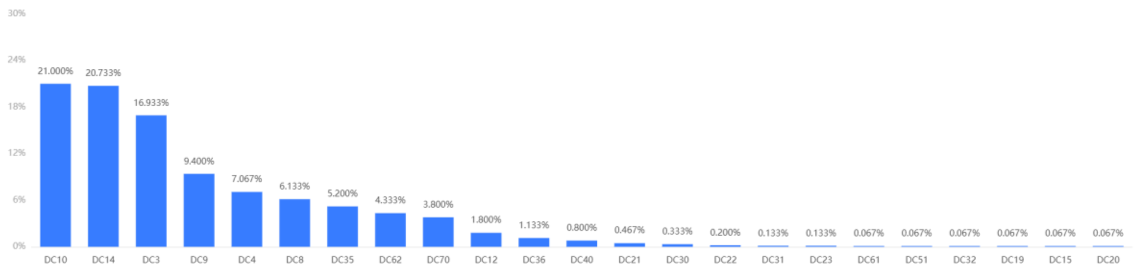

Figure 2: Relationship between DC5 and other lines

Icon description:

The figure above shows the results of the frequency analysis of the relationship between DC5 and other lines, including variables, frequencies, percentages, etc.

3.2 Analysis of experimental results

Fristly, it can be concluded that among the three lines affected by the shutdown, the cargo volume of DC5-DC3 and DC5-DC4 is evenly distributed to the receivers DC3 and DC4 of DC5, and the cargo volume has increased by 71 and 85 pieces, They accounted for 52.21% and 90.48% of the original cargo volume respectively; the cargo volume of the line DC5-DC9 was allocated to the two senders DC2 and DC3 of DC5, and the cargo volume decreased by 71 pieces, accounting for 100% of the original cargo volume[10].

Table 4: Evaluation results of route Topsis model

site	positive ideal solution distance(D+)	negative ideal solution distance(D-)	negative ideal solution distance	to sort
14-8	0.933951	0.971513	0.912298	1
14-9	0.412082	0.700475	0.629605	2
36-4	0.547282	0.473832	0.464035	3
36-10	0.605872	0.488992	0.446642	4
23-4	0.572963	0.449641	0.439701	5
23-10	0.617837	0.472302	0.433249	6
19-4	0.588158	0.444481	0.443043	7
17-4	0.589488	0.411652	0.428317	8
17-10	0.630909	0.470273	0.427062	9
14-10	0.651399	0.455089	0.408622	10
22-4	0.615938	0.423863	0.407639	11
22-10	0.662288	0.454401	0.406918	12
19-10	0.678928	0.431205	0.388428	13
10-4	0.640658	0.399795	0.384252	14
20-10	0.757428	0.391217	0.340592	15
44-8	0.731998	0.346298	0.321153	16
21-10	0.730227	0.345236	0.321013	17
20-4	0.723117	0.334911	0.316544	18
21-4	0.69810	0.320387	0.314569	19
25-10	0.81379	0.364804	0.309524	20

Secondly, by implementing dynamic adjustments, we designed a set of flow plans that meet the requirements, so as to minimize the number of lines whose freight volume changes due to the outage of DC9, and keep the workload of each line balanced. In the case of failure of normal circulation, we provide detailed information on the number of lines affected by the outage of DC9, the volume of goods that cannot be normally circulated, and the network load as follows: routes DC69→DC5, DC69→DC8, DC69→DC14, DC69→ The compliance rate of DC62s cargo volume is 97%, and the average route load rate is about 7%. The remaining cargo volume of all routes is 11280.7. It shows that the overall result after deleting DC9 and adding DC3→DC1 route has no effect, and there is no exceeding the conforming route to meet the actual requirements.

Finally, we can from Table 4 that the top three venues with comprehensive scores are DC10, DC14, and DC4 respectively; the top three routes with comprehensive scores are: DC14→DC8, DC14→DC9, DC36→DC4.

4. Conclusions

For the linear programming model, it is a commonly used optimization method. It has a relatively mature theoretical basis and solution algorithm, and can obtain the optimal solution in a short time; multiple constraints and objective functions can be fused together, Build complex transportation models.

According to the ACO model is a heuristic algorithm, it can find a better solution when solving complex problems, considering the decision-making resolution of opening and closing the route, it can better solve the route planning problem; considering various factors. The weights can be adjusted according to the actual situation to improve the accuracy of the model.

The advantage of the Topsis model is that it is easy to understand, easy to implement, and can obtain relative ranking results based on the weight sum of multiple indicators. At the same time, the model can consider the relative importance of indicators, avoiding the influence of the same weight of different indicators on the results. In addition, the model can effectively conduct decision-making analysis and provide scientific basis for decision-making.

This paper analyzes and solves different problems from multiple angles through different mathematical models and algorithms. This multi-angle analysis method can provide different ideas and solutions, making the problem solving more comprehensive and accurate.

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