Research on the optimisation problem of goods allocation in logistics network based on simulated annealing algorithm

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Abstract. When certain logistics nodes are out of service, based on the processing capacity of the remaining logistics nodes and the transport capacity of the transport routes, it is necessary to design a logistics adjustment scheme to minimise the impact of logistics node shutdown on the logistics network and to guarantee the normal operation of the logistics network. This paper establishes a cargo distribution optimisation model to study the cargo adjustment scheme after the shutdown of logistics node DC5, and uses the simulated annealing algorithm to solve the problem with the objective function of minimising the total amount of cargo change. The final result is: in all the adjusted routes, there is no overloading, and a total of three routes have a load rate of 100 per cent, respectively: 69→8, 69→14, 69→62, of which the load rate of 0 accounted for 66.49 per cent of the routes, and the average load rate is 5.29 per cent. This study helps to improve the emergency response capability of the logistics system and provides scientific support for cargo distribution decisions.

Keywords: Simulated Annealing Algorithm, Cargo Distribution Optimisation, Logistics Network.

1. Introduction

Logistics distribution is an important part of the modern logistics system, it refers to the user's order requirements, in the distribution centre for the distribution of goods, distribution of goods, and the distribution of goods in a timely manner to the consignee's activities [1]. The impact of uncontrollable factors such as bad weather, traffic jam, natural disasters, live broadcasting with goods and large-scale shopping festivals such as "Double Eleven" and "618 Promotion" may lead to some nodes in the logistics network to stop service, line blockage or inefficient distribution, which may bring adverse effects to the e-commerce logistics network. This may cause some nodes in the logistics network to stop service, route blockage or inefficient delivery, which will bring adverse effects to the e-commerce logistics network. In order to cope with such emergencies and ensure the normal operation of the logistics network, it is necessary to carry out effective planning and optimisation of the logistics network, so as to achieve the purpose of reducing logistics costs, saving transport time and sorting sites, improving transport efficiency and ensuring the normal operation of the logistics network.

Facing the problem of distributing goods in unexpected situations that exist in logistics networks, Li Qi [2] By summarising the excellent scholars' papers in the extranet, it is believed that 3PL logistics model can achieve the reduction of the total cost of logistics network through the overall number of linear optimisation model. Nana Wang [3] Considers that the hub-and-spoke network has certain advantages, and reduces the logistics cost by reducing the empty rate, so as to improve the efficiency of logistics activities. Li Zewen [4] It is believed that the simulated annealing algorithm uses the probabilistic selection method in the process of searching for the optimal solution, has the flexibility of choosing the optimal solution, has a strong ability to search within the global range, and has a good, multi-location search ability. The operation of the simulated annealing algorithm is a process of global search followed by local optimisation, Zhou Linfang [5] used this characteristic of simulated annealing algorithm to optimise the self-constructed bi-urban layer model of urban rail transit station siting, and solved the problem of optimising station siting. Ren Peiyao [6] summarised the principle of the simulated annealing algorithm, used the characteristics of this principle and the MATLAB software to carry out multi-objective optimisation of the energy saving system, and then simulated the optimised results in terms of energy consumption, and the data obtained provided a strong support for the research on reducing environmental pollution and finding the optimal energy saving. Jiaqing Li and Lei Le [7] The simulated annealing algorithm is used to optimise the obtained dictionary and sparse coefficients, thus improving the denoising degree of CT and making a contribution to medical imaging. In this paper, a cargo distribution optimisation model is established under the condition that all routes are not overloaded and solved using the simulated annealing algorithm to derive a cargo adjustment scheme after the shutdown of logistics node DC5, so that the cargo stranded due to the shutdown of DC5 continues to circulate.

2. Cargo distribution optimisation model development and solution

2.1. Visualisation and analysis

First of all, the logistics node DC5 is visualised and analysed on the routes into and out of the network, to visualise the position of DC5 in the logistics network and its role, as well as the impact on the network when DC5 is shut down, so as to facilitate the subsequent establishment of the mathematical model, which is visualised as in Fig. 1.

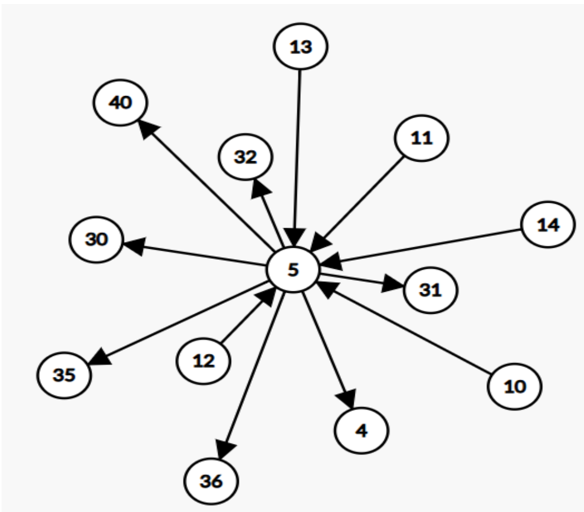

Figure 1. DC5 Visualisation of some of the relevant lines

Consideration of the load on the network when a line is out of service can be expressed in terms of the frequency of use of the line as well as the maximum and minimum carrying capacity. It is also necessary to consider the location of the DC5, if the other areas connected to the DC5 have a low volume of transported goods and the areas connected to it can be connected through other areas, then only some of the routes may be affected when considering the volume of transported goods and other routes will not be affected. However, if the logistics node DC5 is connected to other regions with which there are no additional routes, then this will result in the region not being able to flow the normal volume of goods.

Therefore, a mathematical model based on linear programming can be developed that allows all parcels to flow as normally as possible and keeps the workload on each line as balanced as possible.

2.2. Modelling optimisation of cargo distribution

In this paper, a linear programming model is used to optimise the distribution of cargo volume, and the simulated annealing algorithm is used to solve the problem, so that all the parcels can flow as normally as possible, and at the same time reduce the number of routes where the cargo volume changes, and keep the workload of each route as balanced as possible. Specific modelling steps are as follows.

Assume that after the shutdown of DC5, the goods on DC5-related routes need to be allocated to other routes, where DC5-related routes are i=1,2,...,n, and j=1,2,...,n. Assume that before the shutdown of DC5, the quantity of goods on route i to route j isx_{ij}^{before}, after the shutdown, the quantity of goods on route i to route j isx_{ij}^{last}. c_{ij} Denote the maximum amount of parcels from route i to route j.

After allocating the cargo to other routes, the change in the total amount of cargo needs to be minimised, i.e., the difference between the total amount of cargo before and after the allocation needs to be minimised. Therefore, the objective function can be set to minimise the total amount of change in cargo, i.e., Equation 1.

$$\sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot |x_{ij}^{before} - x_{ij}^{last}| \tag{1}$$

In order to keep the workloads on each line as balanced as possible, it is necessary to limit the total number of goods on each line to a relatively stable range, i.e., the workloads on all lines are as similar as possible. Therefore, the following constraints need to be added:

(1) The number of goods on all routes must satisfy the logistics capacity constraints, i.e., Equation 2.

$$0 \le \sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{ij}^{last} \le c_{ij} \tag{2}$$

(2) Let the proportion of the volume on route DC5 after the closure that is evenly distributed to the other routes be p (the diversion proportion), then the actual volume of parcels on the other routes will be$(1-p)x_{dc5} + x_{ij}$. and is less than the maximum parcel volume on the line, i.e., Equation 3.

$$(1-p)x_{dc5} + x_{ij} \le c_{ij} \tag{3}$$

(3) The number of goods per line per m time periods does not exceed its capacity, i.e., Equation 4.

$$\sum_{t=1}^{m} \cdot \sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{i}^{last}(t) \le \sum_{t=1}^{m} \cdot \sum_{i=1}^{m} \cdot \sum_{j=1}^{n} \cdot c_{ij}(t), t = 1,2,\dots,n \tag{4}$$

(4) The total number of goods on the DC5 related line allocated to other lines is equal to the number of goods on the DC5 related line, i.e., Equation 5.

$$\sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{ij}^{before} = \sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{ij}^{last} \tag{5}$$

(5) The quantity of goods on all routes is as balanced as possible, i.e., Equation 6.

$$\max_{i=1,2,\dots,n}\left(x_{ij}^{last} - \frac{\sum_{i=1}^{n} \cdot \sum_{j=1}^{n} \cdot x_{ij}^{last}}{n}\right) - \min_{i=1,2,\dots,n}\left(x_{ij}^{last} - \frac{\sum_{i=1}^{n} \cdot \sum_{j=1}^{n} \cdot x_{ij}^{last}}{n}\right) \le \sigma \tag{6}$$

Where σ denotes the maximum amount of deviation within the allowed range.

(6) The number of goods per route per time period is a non-negative integer, i.e., Equation 7.

$$x_{ijt}^{last} \epsilon Z \tag{7}$$

In order to make the cumulative daily total of parcels that failed to flow normally at logistics node DC5 shutdown as small as possible. Specifically, if the number of goods on route i exceeds the logistics capacity limit on a given day, the excess portion of the route will be considered to be goods that failed to flow properly, and their number will need to be counted towards the cumulative daily total of parcels that failed to flow properly.

In summary, the model of the required solution is summarised with the objective function as in Equation 8.

$$\min\left(\sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot |x_{ji}^{before} - x_{ij}^{last}|\right) \tag{8}$$

The constraints are as in Equation 9.

$$\begin{cases} 0 \le \sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{ij}^{last} \le c_{ij} \\ \sum_{t=1}^{m} \cdot \sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{i}^{last}(t) \le \sum_{t=1}^{m} \cdot \sum_{i=1}^{n} \cdot \sum_{j=1}^{n} \cdot c_{ij}(t), t = 1,2,\ldots,n \\ \sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{ij}^{before} = \sum_{j=1}^{n} \cdot \sum_{i=1}^{n} \cdot x_{ij}^{last} \\ (1-p)x_{dc5} + x_{ij} \le c_{ij} \\ \max_{i=1,2,\ldots,n}\left(x_{ij}^{last} - \frac{\sum_{i=1}^{n} \cdot \sum_{j=1}^{n} \cdot x_{ij}^{last}}{n}\right) - \min_{i=1,2,\ldots,n}\left(x_{ij}^{last} - \frac{\sum_{i=1}^{n} \cdot \sum_{j=1}^{n} \cdot x_{ij}^{last}}{n}\right) \le \sigma \\ x_{ijt}^{last} \epsilon Z \end{cases} \tag{9}$$

2.3. Solving the model using the simulated annealing algorithm

2.3.1. Theoretical foundations of the simulated annealing algorithm

It can be found that the above planning model is relatively complex, and it is slow and easy to fall into local optimal solutions with traditional algorithms. Heuristic algorithm is a class of optimisation algorithms based on experience or heuristics, this paper uses the simulated annealing algorithm in the heuristic algorithm to seek the optimal approximate solution to the above planning problem.

The simulated annealing algorithm is derived from the principle of solid annealing and is a probability-based algorithm. In the solid annealing process, the solid is heated to a sufficiently high temperature and then allowed to cool. When heated, the particles inside the solid become disordered as the temperature rises, and the internal energy increases; while the particles gradually become ordered as they cool, reaching equilibrium at each temperature, and finally reaching the ground state at room temperature, where the internal energy is minimised [8] [9].

The basic idea of Simulated Annealing Algorithm [10] is to continuously adjust the search direction of the solution during the search process by introducing an annealing process similar to that in physics, in order to find the globally optimal solution. Specifically, the simulated annealing algorithm starts with an initial solution and searches for iteratively, selecting a "neighbour" solution in each iteration and calculating the probability of reaching the neighbour from the current solution. If the neighbouring solution is better than the current solution, the neighbouring solution is accepted as the new current solution with a certain probability, otherwise it is rejected and repeated until the termination condition is met. The key to the simulated annealing algorithm is to set the appropriate initial temperature, cooling factor, and the number of iterations at each temperature. Meanwhile, for different problems, appropriate neighbourhood structures and objective functions need to be defined to guide the search process.

In essence, it can be roughly divided into two layers of loops, iterating repeatedly to generate new solutions, generating new solutions by random perturbations at either temperature during the process of cooling down, and calculating the change in the objective function value to decide whether it is accepted or not. The iterative process is repeated with slow cooling down, where the temperature is slowly reduced after the iteration is completed at a fixed temperature, allowing the algorithm to potentially converge to a globally optimal solution eventually.

2.3.2. Parameter selection

(1) Control parametersT_i Selection of control parameters and initial valuesT_0

In this paper, we choose T_i as the number of increased cargo volume, where each control parameterT_i The corresponding solution isx_i. According to the preliminary analysis of the global optimal solution and search range, combined with the data size, this paper chooses the initial valueT_0 for 200.

(2) Control ParametersR_i Decay function of the

Because of the special nature of this problem, we construct a special decay function to "cool down" the procedure, such as Equation 10.

$$\begin{cases} T_{i+1} = T_i - 1(T_i \geq 1) \\ T_{i+1} = T_i - 0.1(T_i < 1) \end{cases} \tag{10}$$

The commonly used decay function is$T_{i+1} = \alpha T_i, i = 0,1,2$ .... where α can take values from 0.5 to 0.99.

(3) Markov chain length

It is known that the length of the Markov chain should be chosen so as to satisfy a quasi-equilibrium state at each value of the control parameter, and for the simple case it is straightforward to let$L_i = 100n$. Where n is the problem size, here let$n = 5$ n is the size of the problem.$L_i = 500$.

(4) acceptance function as in Equation 11.

$$p(i \to j) = \begin{cases} i \quad , f(i) \leq f(j) \\ exp\left(\frac{f(i)-f(j)}{kL_i}\right), else \end{cases} \tag{11}$$

When Li is larger in the high temperature case, the denominator on the exponent is larger and this is a negative exponent at this point, so the probability of acceptance is close to 1, i.e., a solution that is worse than the current onex_i A new solution that is worsex_j may also be accepted, thus providing the possibility of jumping out of the locally optimal solution.

(5) Stopping conditions, as in Equation 12.

$$L_i = L_f = 0.1 \tag{12}$$

At high temperatures a sufficiently wide-area search has been performed to find the region where the best solution is likely to exist, whereas at low temperatures in a sufficiently localised search it is very likely that the global optimal solution can be found, and therefore a sufficiently small number is set for Lf.

Finally the values of the cooling schedule selected for this paper are shown in Table 1:

Table 1. Cooling schedule

Parameter	Numeric value
Initial temperature	50000
Cooling coefficient	0.98
Stable error range	0.005
End temperature	1
The length of the Markov chain	500

3. Results

Finally, the solution is programmed by MATLAB, and firstly, the variation of cargo volume of some routes is obtained as shown in Fig. 3

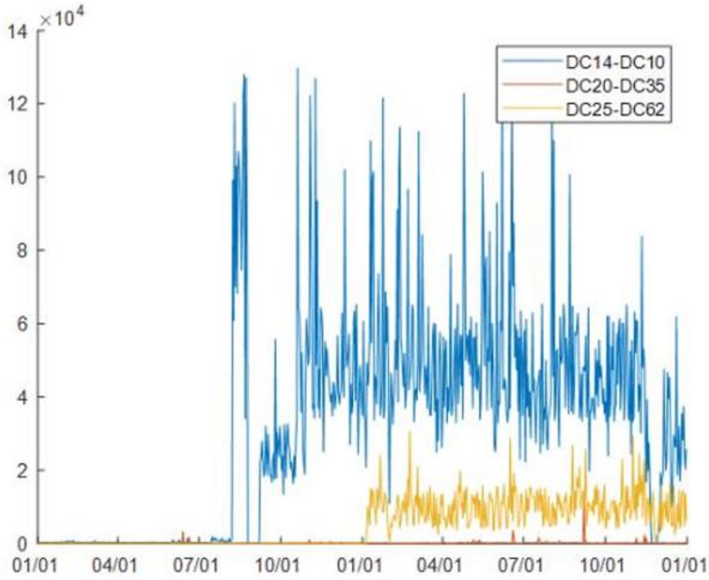

Figure 2. Changes in cargo volume on selected routes

Next, the maximum value of the flow in two years is taken as the capacity, then the average flow in one month is calculated, which is divided by the average utilisation in one month, and finally the daily volume of goods on each route and the workload are calculated, as mathematically defined in Equation 13.

$$W(\%) = Ave/Maxl \tag{13}$$

Where.$W(\%)$ denotes the working load, andAve denotes the monthly average carrying capacity after DC5 is out of service, and$Maxl$ denotes the maximum carrying capacity.

The volume of goods and workload on each line during normal flow is shown in Table 2 below.

Table 2. Quantity of goods in normal flow of routes and workloads Quantity of goods in normal flow of routes and workloads

Route	Go beyond/Surplus cargo (piece)	Working load(%)
69→8	28132	100.00 per cent
69→14	4479	100.00 per cent
69→62	5174	100.00 per cent
69→10	10561	94.86 per cent
23→32	604	57.90 per cent
64→8	1696	54.24 per cent
60→8	21799	53.17 per cent
60→10	7433	52.20 per cent
27→10	16133	51.47 per cent
8→14	32291	51.38 per cent
52→8	3998	50.48 per cent
26→64	11493	49.19 per cent
4→23	3519	48.67 per cent
70→4	385	48.46%
38→64	14273	47.00 per cent
27→8	57062	46.25 per cent
27→14	15669	44.31 per cent
59→62	4037	43.62 per cent
30→14	7599	43.62 per cent
10→4	129442	42.91 per cent

4. Conclusion

The aim of this study is to design a logistics adjustment scheme to minimise the impact of logistics node out-of-service on the logistics network and to ensure normal network operation. In this paper, a cargo allocation optimisation model is established, and an emergency adjustment scheme for cargo allocation is studied for the out-of-service situation of logistics node DC5. It is solved by simulated annealing algorithm with the objective function of minimising the total amount of cargo change. The results show that in all the adjusted routes, there is no overloading and all the goods can flow normally, which indicates that the proposed adjustment scheme can effectively reduce the impact of logistics node deactivation on the logistics network and guarantee its normal operation. This study provides a practical solution to the challenges brought by logistics node out-of-service, which is of great practical significance and helps to improve the emergency response capability, robustness and resource utilisation efficiency of the logistics system, and provides scientific support for logistics management decision-making.

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