Decision onRegional Logistics Network Based on H-S and P-P Network: Taking Tobacco Transportation Logistics as anExample

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Objectives: The logistics hub construction has always been the short board of logistics network planning in China. In order to improve the decision-making efficiency of logistics enterprise's hub selection and reduce its comprehensive operation cost, this paper establishes a cost difference model for hub-and-spoke(H-S) and point-to-point(P-P) networks considering the fixed cost of hubs, transportation and route costs based on the 0-1 integer nonlinear programming.The model aims at minimizing the cost difference between the two networks, and divides the fixed cost of the hubs into three situations: full lease, lease and self-built, and fully self-built. Finally, this paper takes tobacco transportation logistics as an example, and use particle swarm algorithm to solve the model by using tobacco transportation logistics data of a logistics enterprise in Jiangsu Province.The results show that: (i) in the case of complete leasing, the total cost of the H-S network decreases with the increase of the number of hubs, and the cost change has a point of intersection with the total cost of the P-P network;(ii) when the lease and self-build are mixed, the increase is first reduced and then increased, it is U-shaped and has a minimum value, and there are two intersections with the total cost of the P-P network;(iii) the situation of completely self-built and fully leased is just the opposite. This paper takes tobacco transportation logistics as a representative, and provides a reference for logistics companies to choose the appropriate regional logistics network structure and different pivot points.

Key words: Hub-Spoke Network; Point-Point Network; Tobacco transportation logistics; Hub

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On December 21, 2018, the National Logistics Hub Layout and Construction Plan issued by the National Development and Reform Commission and the Ministry of Transportclearly pointed out the problems existing in the development process of China's logistics hubs, including inadequate system planning, scattered planning of existing logistics hub facilities, lack of synergy among hubs, imperfect spatial layout, uneven distribution of logistics hubs, inadequate integration of resources, homogeneous competition and low-level repeated construction in some hubs, extensive development mode and single function, and inability to carry out multi-modal transportation. The logistics hub is a group of logistics facilities and a center for organizing logistics activities that focus on the functions of goods distribution, storage, distribution and transportation, so the construction of a reasonable logistics hub can promote the high-quality development of the logistics industry. However, hub construction is a "short board" in the development of China's logistics network. Therefore, how to plan and design the construction of hubs in logistics network is particularly important.Since China is the world's largest consumer and producer of tobacco, the planning and design of a logistics hub through tobacco transportation logistics is quite representative.In tobacco transportation logistics, some scholars have conducted studies, for example, in econometrics, Yan Chen et al.[1]explored the impact of the application of GIS/GPS network information systems on tobacco logistics distribution costs by using DID and pseudo-DID methods.In terms of simulation modeling, Li, Telang et al.[2]optimize tobacco logistics network distribution by constructing a least-cost tobacco logistics distribution optimization model and the corresponding C-W saving algorithm.

The concept of hub-and-spoke (H-S) network was first put forward by Goldman in 1969 who systematically commented on how to select the best location of the network center with mathematical expressions[3]. After that, when O'Kelly studied American air transport network in 1986, he first established the mathematical model of hub-and-spoke network location and route allocation under single allocation mode, and made an empirical analysis[4]. In 1987, he improved the model and proposed a quadratic integer nonlinear programming model[5]. H-S network is a widely used network type in logistics field. Hub is a node used to transfer goods, where goods are gathered and distributed. The route between hub and hub is called trunk network.Spoke nodes connect hubs, and hubs in H-S networks usually connect many more routes than non-hubs. For example, (a) is a point-to-point network or fully connected network that allows direct interaction between any nodes and can also be transported or traffic converted on any node in the six representative transport networks shown in Fig. 1. Specifically, node 1 can reach node 3 through the transport of node 2; (b) - (e) is a partially connected network that allows some nodes to disconnect. In addition, (a), (b) and (e) may have a hub, (c) and (d) may have two hubs, depending on the interaction of some nodes.

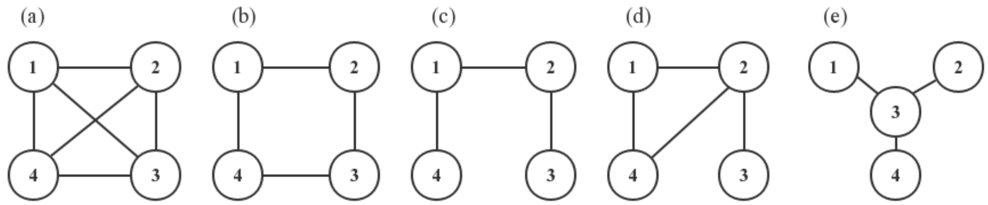

Fig. 1 An example of a hypothetical 4-node network type

A relatively small number of routes and hubs are used in H-S networks to service many interactive origin-destination (O-D) nodes. In the past three decades, many researchers have paid attention to the location of hubs and the design of H-S networks, and have made various theoretical explorations in conjunction with practical problems, which can be roughly divided into the following two categories.

First, the parameters in the quadratic integer linear programming model proposed by O'Kelly in 1987 are improved[6]. 1) The economies of scale effect α in the original model is changed from a constant to a segmented function or other functions. O'Kelly[7]pointed out that there is not only economies of scale in trunk networks between hubs, but also discounts of transportation costs between spoke nodes and hubs.Chen Xiaoxin et al.[8]proposed to replace the fixed discount of the axis with piecewise linear function, so as to solve the location problem of variable discount axis in variable discount simulation.2) Studies considering the existence of competition and cooperation among hubs have been carried out. Mihiro et al.[9] put forward a hub location and allocation model which is suitable for competitive environment, aiming at maximizing corporate profits under the Stackelberg model framework. Zhao Yuzhe et al.[10]established a multi-port pricing strategy model by considering the competition and cooperation between hub ports in the shipping network and port prices, and thought that hub ports should adopt the strategy of "keeping friendly relations with distant states and attacking those nearby" in order to maximize their own interests.3) Studies considering the traffic congestion between hubs have been made.Grove&O'Kelly[11] explained why congestion occurred in H-S network, and put forward corresponding solutions based on a case study of the American air transport network. Marianov&Serra[12] added hub congestion to the optimal location model of hubs in airline networks for the first time on the basis of M=D=c queuing system. Camargo&Miranda[13] discussed the problem of single allocation hub location in congestion situation from the perspectives of network owner and network user, and applied a very effective generalized Benders decomposition algorithm, which could realize the solution of large-scale instance in a reasonable time. Paraskevopoulos et al.[14]ntroduced and described the solution to the variant of Multimodal Network Design Problem (MCNDP), in which node congestion was explicitly considered. Wang Bangjun and Wu Yanfang[15] established the location and allocation model of hub-and-spoke points with single allocation considering congestion and failure based on the 0-1 integer nonlinear programming model, and verified the effectiveness of the model based on a case study of Xianlin area of Nanjing.

Secondly, the structure of H-S network is expanded[4].For example, according to the number of hubs in the network, O'Kelly[2]divided the network into single hub network and multi- hub network, and at the same time divided the network into single allocation H-S network and multi-allocation H-S network according to the connection mode of spoke nodes and hubs. O'Kelly et al.[16] put forward an accurate solution of hub location model for single-allocation and multi-allocation H-S networks. With regard to the capacity limitation of hubs, Skorin-Kapov et al. [17] considered the median problem of multi-allocation p without capacity limitation, and developed a mixed 0-1 linear equation with tight linear programming relaxation.

Most scholars tend to build the cost minimization model of H-S network when selecting the hubs, but often ignore the comparison between H-S network and P-P network or hybrid H-S network. The advantages of H-S networks are: (1) scale economy effect on trunk line network transportation between hubs; (2) smaller overall investment cost for network implementation and operation; and (3) strong traffic control and management functions for hubs (transportation, data, etc.). Meanwhile, the disadvantages of H-S network are: (1) more investment in the hubs (mainly fixed and operating costs); (2) longer distance or time for O-D traffic through the hub than for P-P network connection[18-20].

Unlike the above studies, the innovation of this paper is to compare the relationship between H-S network and P-P network and establish a minimum difference model between the two. In the second section of this paper, the problems to be studied are described. In the third section, under the basic hypotheses, the difference minimization model between H-S network and P-P network is constructed, which takes into account the fixed costs of hubs, transportation costs between nodes and route costs between nodes, in order to find out the best decision-making scheme for logistics enterprises under different fixed costs of hubs. In the fourth section, the official tobacco transportation data of a logistics company is used for example simulation, and the particle swarm optimization algorithm is used to verify the validity of the model. In the last section, the conclusion and prospect are drawn.

Problem Description

In the traditional single allocation pure H-S network optimization, there is a corresponding minimum total cost for any number of hubs p.In order to make the model more consistent with reality, the fixed cost, network transportation cost and route cost of hubs are taken into account in this paper.With the increase of the number of hubs, the distance of OD traffic will be correspondingly reduced, which will reduce the transportation costs and route costs, but at the same time, the overall fixed costs of hub points will be correspondingly increased.If only transportation costs and route costs are considered, H-S network is better than P-P network due to the economies of scale effect between hubs.It is not possible to directly determine which one is better when the fixed costs at the hubs are taken into account.

Therefore, in this paper, under different fixed costs of hubs, a model of minimizing the difference between the total costs of two networks is constructed, and the corresponding number of hub points p^* is found out. On this basis, different distribution modes of networks and hubs are selected.

METHODS

Basic Hypotheses and Symbol Description

In order to simplify the model and conform to the actual problems, the following basic hypotheses are made on the basis of referring to the existing literature:

H1: Without considering the impact of natural disasters and other emergencies on the H-S network structure, the number of hubs is unknown and uncertain;

H2: In the H-S network, each non-hub has and only has one hub connected with it, and all hubs are connected in pairs;

H3: In the H-S network, regardless of the differences in internal functions, market position and social reputation among the hubs, there are no restrictions on the size of each hub and its reserves and the fixed costs are the same;

H4: All OD traffics are allowed to be transported by single-point transit and two-point transit, but direct transportation cannot be used between non-hubs.

H5: Considering that each node in the P-P network also has some functions of the hub, it is assumed that the fixed cost of each node in the P-P network is less than that of the hub in the H-S network, and the ratio of the two is set as $1/c$, and $c > 1$.

To facilitate the construction of the mathematical model of the problem, the following symbols are defined, as shown in Tables 1 and 2:

Table 1
Model parameters

Parameters	Descriptions
W_{ij}	The freight traffic from node i to j, $W_{ij} = W_{ji}$, $W_{ii} = 0$
C_{ij}	Freight transportation cost/traffic/distance from node i to j, $C_{ij} = C_{ji}$, $C_{ii} = 0$
L_{ij}	The transportation distance from node i to j, $L_{ij} = L_{ji}$, $L_{ii} = 0$
A_{ij}	Path cost/ traffic/ distance from node i to j, $A_{ij} = A_{ji}$, $A_{ii} = 0$
F_{h-s}	The fixed cost for each hub in the H-S network
a	The economies of scale of freight transport between any two hubs on a trunk network, 0<a<1
b	The route discount in the trunk network where the hub points are connected
c	The ratio of fixed costs of hubs in H-S network to those of hubs in P-P network.
	$Z_{p-p} = \sum_i \sum_j W_{ij} C_{ij} L_{ij} + \sum_i \sum_j W_{ij} A_{ij} L_{ij} + \frac{n}{c} F_{h-s}$
Z_{p-p}	Calculating the total cost when the transportation path of the OD traffic in the P-P network is ij, wherein the first part represents the total transportation cost of goods from the node i to j, the second part represents the total route cost of goods from the node i to j, and the third part represents the fixed cost of the node.
$Z_{h-s} = \sum_i \sum_j \sum_k W_{ij} X_{ik} L_{ik} (C_{ik} + A_{ik}) + \sum_i \sum_j \sum_m W_{ij} X_{jm} L_{jm} (C_{jm} + A_{jm}) + \sum_i \sum_j \sum_k \sum_m W_{ij} X_{ik} X_{jm} L_{km} (aC_{km} + bA_{km}) + pF_{h-s}$	
Z_{h-s}	Calculating the total cost of ikmj as the transportation path of OD traffic in the H-S network, wherein the first part represents the transportation cost and the route cost from the node i to the first hub k, the second part represents the transportation cost and the route cost from the second hub m to the node j, the third part represents the transportation cost and the route cost from the hub k to the hub m, and the fourth part represents the fixed cost of the hubs.

Table 2
Decision variables of the model

Decision variables	Descriptions
X_{ik}	The distribution of the non-hubs, if the non-hub i is assigned to the hub k, the value of X_{ik} is 1, otherwise it is 0.
X_{kk}	The distribution of hubs, if the node k is selected as a hub, the value of X_{ik} is 1, otherwise it is 0.

p	The number of hubs.

Modeling

$$Z(x,p) = min\left|(minZ_{h-s} - Z_{p-p})\right| \quad (1)$$

$S.t$

$$(n-p+1)X_{kk} - \sum_i X_{ik} \geq 0 \; forallk \quad (2)$$

$$\sum_k X_{ik} = 1 \qquad foralli \quad (3)$$

$$\sum_k X_{kk} = p \; forallk \quad (4)$$

$$X_{ik} \in \{0,1\} foralli, k \quad (5)$$

$$0 \leq a \leq 1, 0 \leq b \leq 1 \quad (6)$$

$$Z_{p-p} = \sum_i \sum_j W_{ij} C_{ij} L_{ij} + \sum_i \sum_j W_{ij} A_{ij} L_{ij} + \frac{n}{c} F_{h-s} \quad (7)$$

$$Z_{h-s} = \sum_i \sum_j \sum_k W_{ij} X_{ik} L_{ik}(C_{ik} + A_{ik}) + \sum_i \sum_j \sum_m W_{ij} X_{jm} L_{jm}(C_{jm} + A_{jm}) + \sum_i \sum_j \sum_k \sum_m W_{ij} X_{ik} X_{jm} L_{km}(aC_{km} + bA_{km}) + pF_{h-s} \quad (8)$$

The objective function (1) is to minimize the error of the total cost between H-S network and P-P network, in which the number and distribution of hubs and the connection mode between nodes are independent variables. Constraint (2) ensures that only when node k is selected as a hub can other non-hubs be connected with it. Constraint(3) ensures that each non-hub can only be connected with one hub, that is, direct transportation cannot be used between two non-hubs. Constraint (4) indicates that there arephubs set. Constraint (5) means that if node i is connected with hub k, $X_{ik} = 1$, otherwise $X_{ik} = 0$. Constraint (6) indicates the scope of economies of scale. Constraints (7) and (8) respectively calculate the total cost of OD traffic in P-P network and H-S network.

Solution Method for Model

In this paper, the model solving is divided into two steps: the first step is to solve the traditional H-S network location and path optimization problem, in order to find out the corresponding minimum total cost of H-S network under a specific number of hubs p. Because this problem is a 0-1 integer quadratic programming problem and proved to be NP-hard problem, it is difficult for the traditional calculation method to find the global optimal solution in a short time. Therefore, in this paper, the particle swarm optimization algorithm is used to solve this model, because it has the advantages of fast convergence, high precision and easy to master as an optimization algorithm. The second step is to use enumeration method to find out the minimum value of the total cost difference between the H-S network and the P-P network. At this time, the corresponding number of hubs p^* has certain reference significance for logistics enterprises.

DATA ANALYSIS

Data Sources

In this paper,the official data on tobacco logistics transportation from a logistics company in Jiangsu Province is used. The corresponding OD(Origin-Destination) traffic matrix of goods transportation in 13 cities in Jiangsu Province is shown in Appendix 1, and the transportation distance between cities is shown in Appendix 2.

Data Hypotheses

(1)According to the literature consulted, the economies of scale effect a=0.8 and the route discount b=0.8are assumed in the process of calculating the transportation cost.

(2)In the calculation of transportation cost, it is assumed that the transportation cost per unit traffic/unit distance is C=0.1.

(3) In the calculation of route cost, it is assumed that the route cost per unit traffic/unit distance is A=0.09.

(4)Since each node in the P-P network has some functions as a hub, and the fixed cost of these nodes is smaller than that of the hub, it is assumed that the proportional coefficient between them is c=4.

(5)In this paper, the difference between the total cost of H-S network and P-P network is calculated in three different situations, and it is assumed that the fixed cost of the hub is 0.2 million yuan when the logistics enterprise leases the hub, the fixed cost is 1.5 million yuan when the hubs are released and self-built, and the fixed cost is 5 million yuan when the hubs completely self-built.

Computational Results and Analysis

Let the number of hubs p in the model be a constant value, and take different numbers of hubs to find out how the corresponding transportation cost, route cost, fixed cost and total network cost change. Compare the total cost of H-S network obtained in the first step with the total cost of P-P network, calculate the absolute value of the difference, and find out the minimum value. The following three different situations are analyzed:

(1)By exploring the feasible solutions and hubs obtained when leasing the hubs (F = 0.2 million yuan), the expenses of the P-P network and the H-S network are obtained.The cost of P-P network is shown in Table 3, and the cost of H-S network is shown in Table 4.

Table 3
Costs of P-P network (yuan)

Transportation cost	Route cost	Fixed cost	Total costs
15589800	14030800	650000	30270600

Table 4
Costs of H-S network for different hub numbers (yuan)

p	Transportation cost	Route cost	Fixed cost	Total costs
1	17886700	16098000	200000	34184700
2	15958600	14362700	400000	30721300
3	14705400	13234900	600000	28540300
4	14076900	12669200	800000	27546100
5	13585700	12227100	1000000	26812800
6	13304100	11973700	1200000	26477900
7	13047100	11742400	1400000	26189600
8	12775100	11497600	1600000	25872700
9	12539900	11285900	1800000	25625900
10	12350900	11115800	2000000	25466600
11	12221600	10999400	2200000	25421000
12	12116500	10904900	2400000	25421400

The results in Table 4 show that in the H-S network, with the increase of the number of hubs, the route length of goods transportation is reduced, and the transportation cost and route cost are correspondingly reduced. At the same time, the fixed cost of the hub is increasing. In this case, the increase of hub fixed cost is far less than the decrease of transportation and route cost, so the total network cost is also decreasing.

However, in the actual situation, if logistics enterprises set all nodes as hubs, the cargo transportation traffic of trunk network between hubs will be correspondingly reduced, which cannot reflect the economies of scale of trunk network. Because the economies of scale effect a is set as a fixed value in this paper, the simulation result of this example is ideal.

In Fig. 2, the total costs of P-P network and H-S network are compared. When $|(Z_{h-s} - Z_{p-p})|$ is the smallest, the corresponding p^*=2 is reached at this time, and when 1≤p≤2, the P-P network is selected. When 3≤p≤13, H-S network is selected.

When the number of hubs p=2, the optimal network location planning and path allocation diagram (Fig. 3) and the model solving iterative process diagram (Fig. 4) are obtained. The distribution of spoke nodes is shown in Table 5.

(2) By exploring the feasible solution and hub situation obtained when hubs are leased and self-built (F = 1.5 million yuan), the cost of P-P network is shown in Table 6, and the cost of H-S network is shown in Table 7.

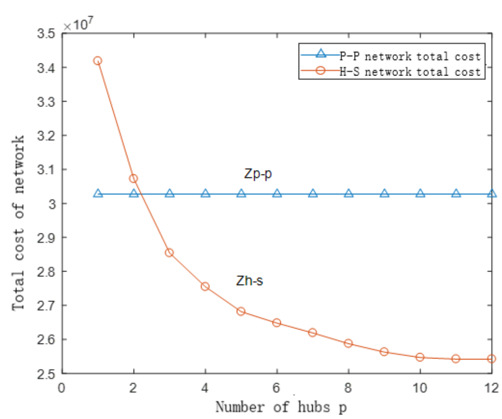

Fig. 2 Comparison between total costs of P-P network and H-S network

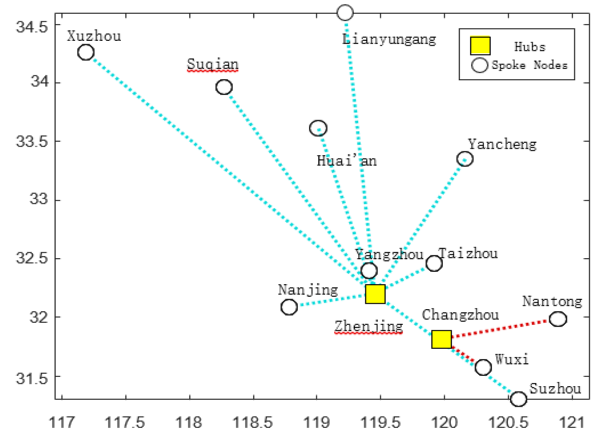

Fig. 3 Network location planningand path allocation when leasing hubs (p=2)

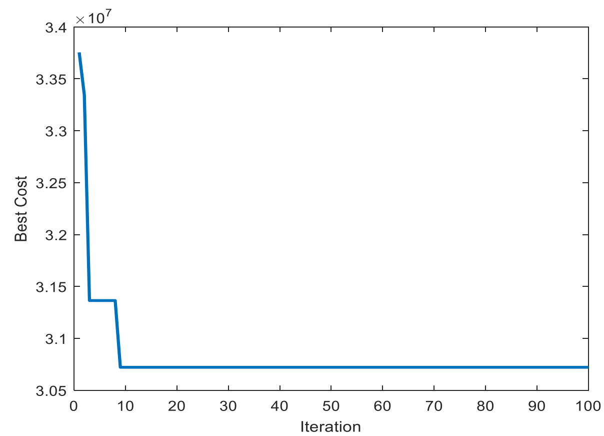

Fig. 4 Iterative process of model solution when leasing hubs (p=2)

Table 5
Distribution of spoke nodes when leasing hub (p=2)

Hub node	Spoke node
Zhenjiang	Suzhou, Nanjing, Yangzhou, Taizhou, Yancheng, Lianyungang, Huai'an, Suqian, Xuzhou
Changzhou	Wuxi, Nantong

Table 6
Costs of P-P network

Transportation cost	Route cost	Fixed cost	Total costs
15589800	14030800	4875000	34495600

Table 7
Costs of H-S network for different hub numbers

p	Transportation cost	Route cost	Fixed cost	Total costs
1	17886700	16098000	1500000	35484700
2	15958600	14362700	3000000	33321300
3	14705400	13234900	4500000	32440300
4	14076900	12669200	6000000	32746100
5	13585700	12227100	7500000	33312800
6	13304100	11973700	9000000	34277900
7	13047100	11742400	10500000	35289600
8	12775100	11497600	12000000	36272700
9	12539900	11285900	13500000	37325900
10	12350900	11115800	15000000	38466600
11	12221600	10999400	17500000	39721000
12	12116500	10904900	19000000	41021400

According to Table 7, in this case, the decreasing range of transportation and route costs in H-S network gradually decreases, and the fixed costs at hubs constantly increase, so the total network costs first decrease and then increase, showing a U-shaped relationship. As shown in Fig. 5.

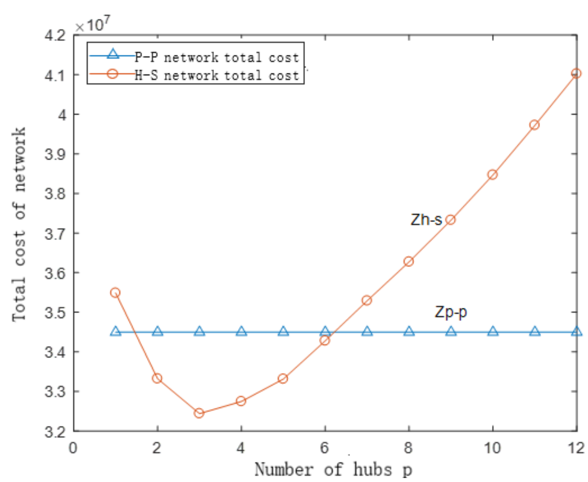

Fig.5 Comparison between total costs of P-P network and H-S network

When the number of hubs p=3, the total network cost is the smallest, which is 32,440,300 yuan. The best network site selection plan and route allocation diagram at this time is obtained (Fig. 6). The three hubs are Huai'an, Zhenjiang and Changzhou respectively. Xuzhou, Suqian and Lianyungang are connected with Huai'an. Wuxi and Nantong are connected with Changzhou, while Nanjing, Yangzhou, Taizhou, Yancheng and Suzhou are connected with Zhenjiang. Among them, the hub connecting Suzhou is Zhenjiang, which is far away, because in this case, the distance between Suzhou and several other cities in northern Jiangsu can be reduced to reduce the total cost.

When $|(Z_{h-s} - Z_{p-p})|$ is minimum, the corresponding p^*=6is obtained, and the optimal network location planningand path allocation diagram is obtained (Fig. 7). When 1≤p≤2, P-P network is selected. When 3≤p≤7, H-S network is selected. When 8≤p≤13, P-P network is selected.

(3)By exploring the feasible solution and hub situation obtained when hubs are leased and self-built (F = 5 million yuan), the costs of P-P network and H-S network areobtained.The cost of P-P network is shown in Table 8, and the cost of H-S network is shown in Table 9.

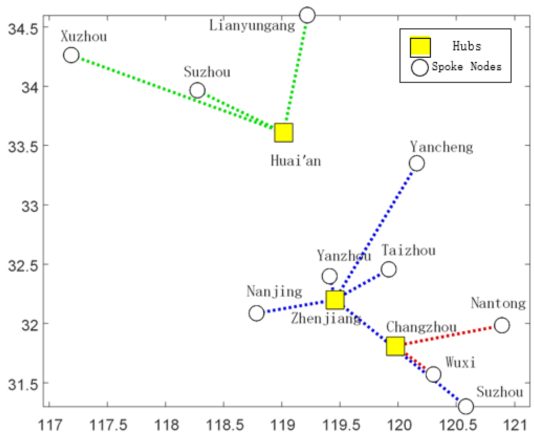

Fig. 6 Network location planningand path allocation when hubs are leased and self-built (p=3)

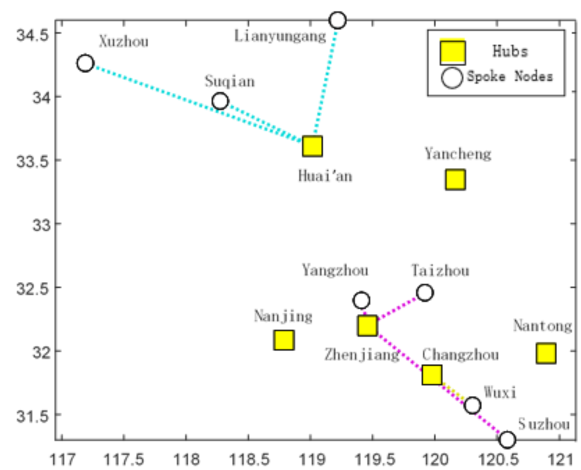

Fig. 7 Network location planning and path allocation when hubs are leased and self-built (p=6)

Table 8
Costs of P-P network (yuan)

Transportation cost	Route cost	Fixed cost	Total costs
15589800	14030800	16250000	45870600

Table 9
Costs of H-S network for different hub numbers (yuan)

p	Transportation cost	Route cost	Fixed cost	Total costs
1	17886700	16098000	5000000	38984700

2	15958600	14362700	10000000	40321300
3	14705400	13234900	15000000	42940300
4	14076900	12669200	20000000	46746100
5	13585700	12227100	25000000	50812800
6	13304100	11973700	30000000	55277900
7	13047100	11742400	35000000	59789600
8	12775100	11497600	40000000	64272700
9	12539900	11285900	45000000	68825900
10	12350900	11115800	50000000	73466600
11	12221600	10999400	55000000	78221000
12	12116500	10904900	60000000	83021400

According to the results in Table 9, in this case, the reduction of transportation and route costs is less than the increase of fixed costs of the hub, so the total network costs are increasing. Comparison between H-S network and P-P network is as shown in Fig. 8.

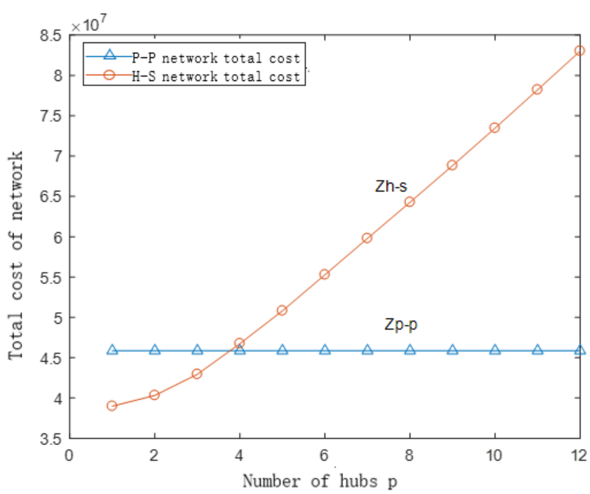

Fig.8 Comparison between total costs of P-P network and H-S network

When $|(Z_{h-s} - Z_{p-p})|$ is the minimum, the corresponding p^*=4 is reached. When 1≤p≤3, H-S network is selected. When 4≤p≤13, P-P network is selected.

When the number of hubs is p=4, the network location planning and path allocation diagram is obtained (Fig. 9).Table 10 shows the hub allocation problem of the model.

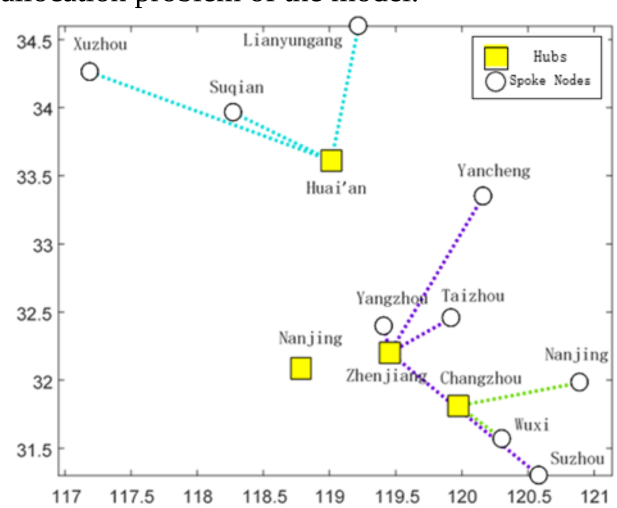

Fig. 9 Network location planningand path allocation when hubs self-built (p=4)

Table 10
Allocation of spoke nodes when hubs are self-built (p=4)

Hub node	**Spoke node**
Zhenjiang	Yangzhou, Taizhou, Yancheng, Suzhou
Changzhou	Wuxi, Nantong

Huai'an	Xuzhou, Suqian, Lianyungang
Nanjing	None

CONCLUSIONS AND PROSPECTS

Logistics enterprises need to consider factors such as service efficiency and cost when choosing transportation network structure, because a suitable logistics transportation network should have higher service efficiency, but at the same time, enterprises all aim at minimizing cost. Therefore, in this paper, taking tobacco transportation logistics as an example and referring to other literature,The total cost of tobacco transportation for logistics companies is divided into transportation cost, route cost and fixed cost of hubs, the H-S network and P-P network are compared and the minimum value of the difference and the corresponding p^* are found out under the three scenarios of leasing hubs, the mixture of leasing and self-built hubs, and completely self-built hubs, which provide a certain reference for logistics enterprises to select the transport network structure.

The following conclusions are drawn through example analysis:(1) When logistics enterprises choose to lease hub points, the total cost of H-S network decreases with the increase of hub points, and there is a minimum value of $|(Z_{h-s} - Z_{p-p})|$, at which time the number of corresponding hubs is p^*. Given the number of hubs p, logistics enterprises should choose P-P network when$1 \leq p < p^*$, and H-S network when $p^* \leq p < n$. (2) In case of mixed leasing and self-built hubs, the image of Z_{h-s} presents a u-shaped relationship with the increase of the hub, with a minimum value and two intersections p^{*1} and p^{*2}. Moreover, the P-P network is selected when $1 \leq p \leq p^{*1}$, the H-S network is better when $p^{*1} < p \leq p^{*2}$, and the P-P network is better when$p^{*2} < p < n$. (3) When the hub is completely self-built, the total cost of H-S network increases with the increase of hub. Logistics enterprises should choose H-S network when$1 \leq p < p^*$, and P-P network when$p^* \leq p < n$.

In this paper, the P-P network and pure H-S network are compared only from three costs: transportation cost, line cost and fixed cost of hub.Actually, the cost of traffic delay should also be considered in the total cost of H-S network to make the model more realistic. At the same time, the hybrid H-S network should be further studied and compared with P-P network and pure H-S network.

Conflicts of Interest Disclosure Statement

The authors declare no conflict of interest in the authorship or publication of this work.

Author Declaration

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Appendix

Appendix 1aOD traffic between nodes (tons)

	Nanjing	Wuxi	Xuzhou	Changzhou	Suzhou	Nantong	Lianyungang
Nanjing	0	2037	3509	13829	5312	7238	5127
Wuxi	3063	0	2961	10364	4659	5715	3380
Xuzhou	4554	1589	0	906	993	711	693
Changzhou	11288	1040	2841	0	2220	58830	1283
Suzhou	79070	6611	10388	22476	0	17631	20619
Nantong	13638	9629	1176	3800	1335	0	2549
Lianyungang	1199	332	257	1029	1059	942	0
Huai'an	9633	14402	323	3188	4013	315	9521
Yancheng	2205	1199	216	942	257	332	398
Yangzhou	9285	4610	779	900	1259	638	770

Zhenjiang	45540	1589	906	993	711	693	1922
Taizhou	3464	9521	213	1287	9633	323	107
Suqian	1125	884	507	531	2649	260	689

Appendix 1bOD traffic between nodes (tons)

	Huai'an	Yancheng	Yangzhou	Zhenjiang	Taizhou	Suqian
Nanjing	5225	17150	1867	10797	7385	3215
Wuxi	3624	13205	3236	31898	8670	1766
Xuzhou	1922	1586	2124	981	836	236
Changzhou	2051	4434	1581	8573	942	257
Suzhou	8631	1410	7303	36614	9630	14988
Nantong	1196	1439	7509	8508	2994	1431
Lianyungang	398	1658	717	5826	205	216
Huai'an	0	173	3464	210	213	1287
Yancheng	1029	0	1658	717	1059	939
Yangzhou	3105	4496	0	6282	1103	546
Zhenjiang	1586	2124	981	0	836	236
Taizhou	315	173	3188	4013	0	210
Suqian	410	897	462	173	800	0

Appendix 2a Distance between nodes (km)

	Nanjing	Wuxi	Xuzhou	Changzhou	Suzhou	Nantong	Lianyungang
Nanjing	0	199	344	159	252	310	305
Wuxi	199	0	514	40	53	103	415
Xuzhou	344	514	0	479	575	571	225
Changzhou	159	40	479	0	93	102	415
Suzhou	252	53	575	93	0	99	470
Nantong	310	103	571	102	99	0	388
Lianyungang	305	415	225	415	470	388	0
Huai'an	185	296	218	271	357	328	122
Yancheng	281	239	374	249	281	192	196
Yangzhou	101	147	388	107	218	193	292
Zhenjiang	75	124	396	84	77	184	314
Taizhou	156	129	410	129	197	141	315
Suqian	259	394	120	364	464	423	172

Appendix 2b Distance between nodes (km)

	Huai'an	Yancheng	Yangzhou	Zhenjiang	Taizhou	Suqian
Nanjing	185	281	101	75	156	259
Wuxi	296	239	147	124	129	394
Xuzhou	218	374	388	396	410	120
Changzhou	271	249	107	84	129	364
Suzhou	357	281	218	77	197	464
Nantong	328	192	193	184	141	423
Lianyungang	122	196	292	314	315	172
Huai'an	0	130	172	195	192	97
Yancheng	130	0	186	211	174	227
Yangzhou	172	186	0	25	52	269
Zhenjiang	195	211	25	0	77	282
Taizhou	192	174	52	77	0	289
Suqian	97	227	269	282	289	0