

Research Article

Allocating Cost to Freight Carriers in Horizontal Logistic Collaborative Transportation Planning on Leading Company Perspective

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Interest has been raised by the recent identification of cooperation cost through collaborative planning in horizontal logistics operations. Even though cooperation cost can be realized, one key question exists: how should cooperation cost be divided among a group of collaborating companies. In this article, the question is studied in a centralized framework context. We divide the participants into two groups, leading companies (LC) and nonleading companies (NLC), and propose five fair distribution rules from the perspective of leading companies. According to these distribution principles, we developed an allocation method called Leading-idealism Cost Allocation Model (LiCAM) and compared it with three existing classic allocation mechanisms which violate some of these criteria are discussed. Computational results show that our method has acceptable calculation time, stability, consistency, and monotony. Our model can fully reflect the value as a leading company which is consistent with the actual practice requirements. We also illustrate the value and operability of our model by discussing the number of leading companies and the size of the alliance.

1. Introduction

With the rapid development of the world economy and the advancement of science and technology, the modern logistics industry has become an important part of the booming modern economy worldwide [1]. Due to the globalization and network characteristics of the logistics industry, it is difficult for any logistics company to cover all areas and to efficiently undertake a variety of transportation modes at the same time, so the cooperation between logistics companies is continuously deepening. There are generally two forms of cooperation, namely, horizontal cooperation and vertical cooperation. The European Union [2] defines horizontal cooperation as “an agreement or concerted practice (y) between companies operating at the same level (s) in the market.” Cooperating companies can compete with each other or not. But, they should perform the same type of

activities and/or services rather than complementary activities and/or services, which is related to vertical cooperation. A definition of horizontal cooperation based on logistics was proposed by Cruijssen et al. [3]. He concluded that horizontal logistics are two or more firms performing a comparable logistics function at the same level of the supply chain on the landside.

Horizontal logistic is an effective way to improve logistic operations. There are a number of papers reporting on horizontal logistic transportation studies within specific contexts, such cooperative planning in express carrier networks [4], collaborative transportation planning of less-than-truckload freight [5], specific possibility for horizontal cooperation by planning linked deliveries [6], forest fuel transportation collaboration in Sweden [7], and request selection and exchange approach for carrier collaboration based on auction of a single request [8].

In order to realize cooperation, in practice, two methods can be used to solve the problem of cooperative logistics: centralized method and decentralized method. In the centralized method, multiple carriers reach an agreement and form a cooperative alliance with the coordinator responsible for making cooperative transportation plans for them. The coordinator redistributed the alliance's transportation request to all carriers as a way to maximize the total profit of the alliance under the restriction that each request is allocated to at most one carrier. As for decentralized methods, the framework involves two types of participants, namely, auctioneers and bidders (carriers). Among them, the auctioneer's function is to determine and update the price of each service request and to maximize the total profit. Each bidder chooses its best requirements according to the price proposed by the auctioneer to maximize its personal profit. The centralized framework can usually bring more profits to the alliance than the total profits generated by the decentralized framework [9], while the decentralized methods offer carrier more autonomy.

The cooperative gaming method as the mainstream method can be used to solve the problem of cost allocation. In recent years, this issue has caused widespread concern. Cooperative game theory has some well-known solutions concepts, such as the core theory, the Shapley value theory proposed by Shapley [10], and the nucleolus theory put forward by Schmeidler [11]. The core theory requires the rationality of individuals, groups, and alliances, and these attributes are the basis for cost allocation in most literature. However, two drawbacks are visible because core is not unique and it will probably be empty. The Shapley value method is used in many literatures to conduct cost allocation or profit sharing ([12, 13]). The nucleolus cost-allocating method to solve routing problems also was studied in many articles, e.g., Yin et al. [14]. The scholars discuss some new methods based on the classic solution concept. Frisk et al. [15] studied the issue of forest transportation cooperative planning and proposed the EPM (equal profit method). Audy et al. [16] proposed four business models to study on coalition formation and cost/savings allocation. Naber et al. [17] developed four emission allocation methods. Sun et al. [18] considered a contribution constrained packing model for cost allocation. Liu and Cheng [19] developed LCAM (location cost allocation model), which take geographical location factor into account.

2. Problem Descriptions

In practice, common scenarios for horizontal logistics collaborative transportation planning can be described as follows. The Figure 1 shows a typical non-cooperative scenario where each freight carrier designs its own set of routes to deliver its own customers. In contrast, the Figure 2 shows the same routing problem in a cooperative scenario, where each distribution unit is reasonably assigned to its adjacent logistics facility. It also realizes to improve actual utilization of vehicles during a roundtrip and reduce the crisscross transportation phenomenon in complex transportation networks. We can find practical examples from the

article Krajewska et al. [20]; Frisk et al. [15]; Perez-Bernabeu et al. [21], and so on. Obviously, prior to horizontal cooperation, each carrier had an independent cost. After horizontal cooperation, all carriers formed an alliance to complete the task together, which resulted in lower total cost.

In this article, it leads to a lower cost for the alliance as a whole using the centralized collaboration framework. Under this framework, there are two roles in the alliance, one is leading company (s) (LC) and the other is participant (NLC). The responsibility of the leading company is to develop participants in order to form an alliance, collect information about supply and demand, formulate a feasible operation plan, and make each participating company put the cooperation plan into practice. Two major problems can be summarized to be solved. One problem is the collaborative planning. The problem to achieve the lowest overall cost for the carriers has been studied in many literatures, including but not limited to vehicle routing optimization or inventory routing problems. Another problem lies in the equitable allocation of the total cost amount to each carrier concerned, leading to a lower cost for each carrier as a result of the cooperation. Cruijssen et al. [22] and Leitner et al. [23] both point to fair cost allocation as one of the most important obstacles to horizontal logistics. The paper emphatically probes into the second problem. More details on the allocation rule are provided in Section 4. Our concept of model allows allocating cost to freight carriers on leading company perspective according to the specific context of such a collaborative organization.

3. Allocation Methods

3.1. Core Allocation. The concept of core has some of the most frequently used properties. A participant's subset is denoted with coalition S , and all participants are denoted by grand coalition N . Assume that every participant has the chance to generate and cooperate in coalitions. In the case of cooperation of coalition S , we can generate the common cost $C(S)$. According to the cooperative game theory, such function of cost is referred to as characteristic cost function, and every participant is known as a player. Therefore, the problem of cost allocation can be considered as a cooperation game.

A cost allocation method is applied to the separation of total cost, i.e., $C(N)$. Among the participants, $j \in N$ is said to be efficient, that is, $\sum_{j \in N} y_j = C(N)$, in which y_j denotes the cost which is allocated to the participant j . A cost allocation can be considered as individual rational if there is no participant which makes a payment higher than the "stand alone cost" (that is, the cost of the participant), when no coalition is generated. If we put it mathematically, we can express the property as $y_j \leq C(\{j\})$. The core of the game is identified as those who meet the requirements of the cost allocation. It is considered that the cost allocation at the core is stable:

$$y_j \leq C(\{j\}), \quad (1)$$

$$\sum_{j \in N} y_j = C(N). \quad (2)$$

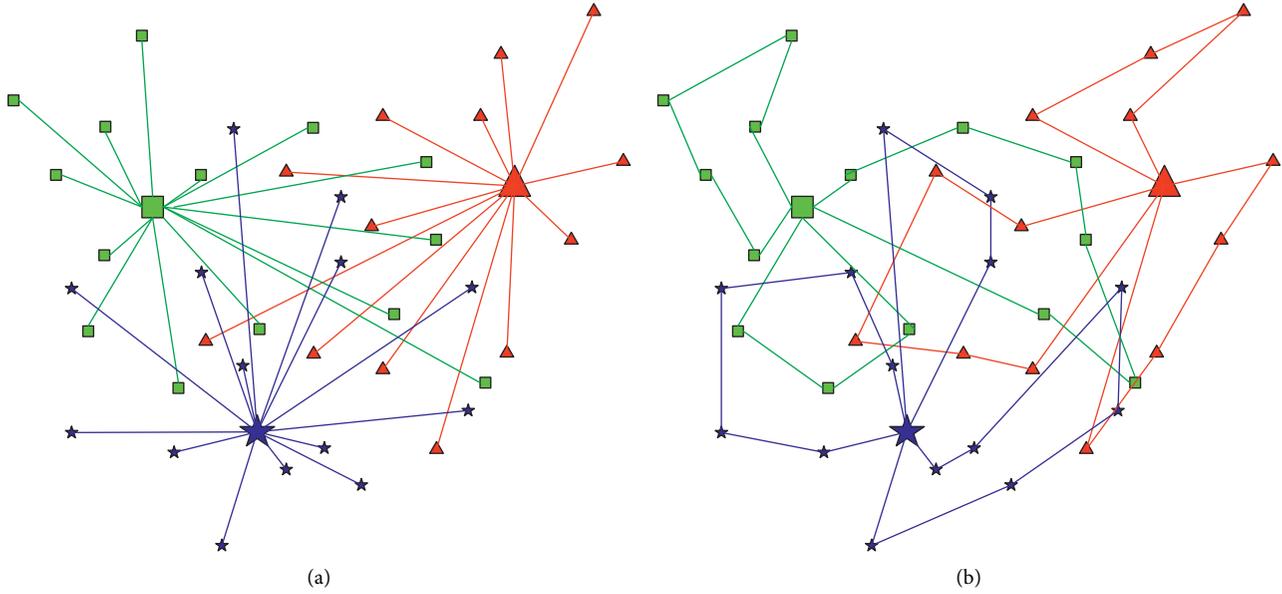


FIGURE 1: Non-cooperative scenario: each provider delivers its own customers.

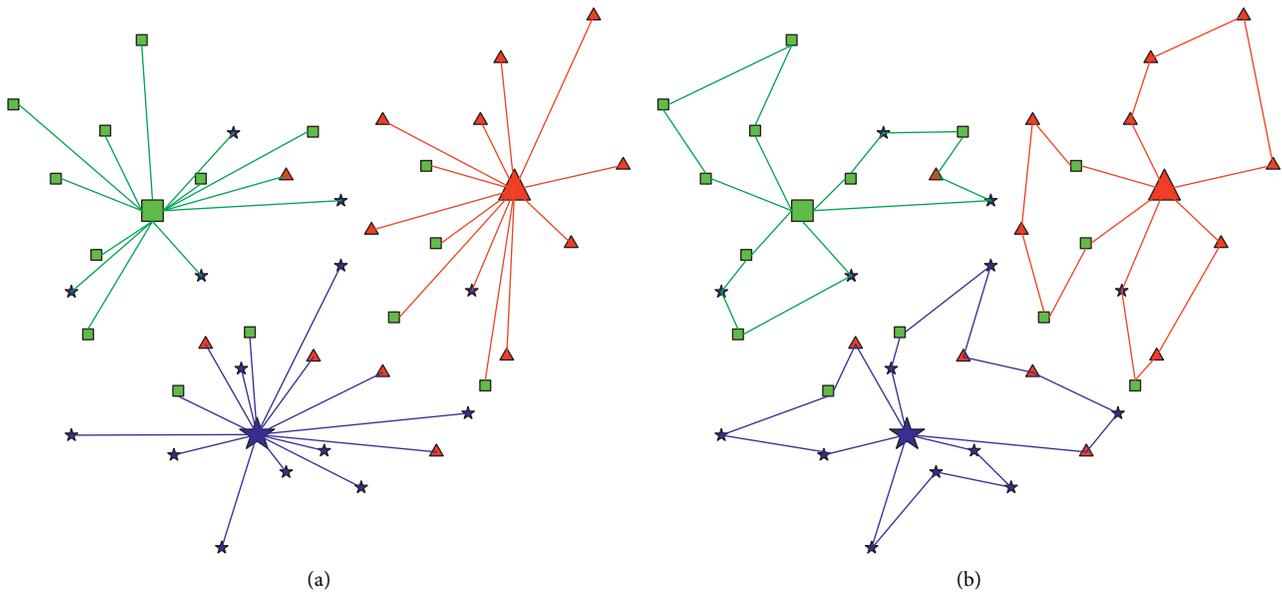


FIGURE 2: Cooperative scenario: each customer is delivered by the closest provider.

3.2. *The Shapley Value.* The Shapley value is a concept of solution, with which we can have one and only solution to the problem of cost allocation. According to the formula below for calculation, it is assumed that only one participant j is accessible to the grand coalition each time. As the coalition is entered by every participant, the marginal cost is allocated, which suggests that, through such entry, the total coalition cost is increased. The amount received by participants in this program depends on the order in which participants joined. The cost assigned to participant j is equal:

$$y_j = \sum_{S \subset N, j \in S} \frac{(|S| - 1)! (|N| - |S|)!}{|N|!} [c(S) - c(S - \{j\})], \tag{3}$$

where $|\cdot|$ shows the number of participants in the coalition considered. The sum of this formula is equal to that over all coalitions S that include the participant j . The value of $c(S) - c(S - \{j\})$ refers to the increase of the cost of the alliance with the increased the participant j , which is expressed by the marginal cost of participant j regarding the coalition

$S - \{j\}$. With Shapley value, we can obtain one and only cost allocation. Nevertheless, it cannot be guaranteed that it is stable. For example, the individual rationality is not satisfied necessarily.

3.3. The Nucleolus. The nucleolus refers to the allocation x , and it is individually rational and efficient; for this reason, in all allocations, $f(x)$ is a lexicographic minimum. As reported by Schmeidler [11], a coalition excess shows the “attitude” that the coalition has towards such allocation, while the nucleolus could be considered as the allocation which is most accepted. The nucleolus is located in the core and it is unique, if the core is not empty.

To identify the nucleolus, a method adopted by Engevall et al. [24] is used here. With the method, different problems of linear programming (LP) are solved one by one. First, an allocation is identified by having the smallest excesses maximized. It should be noted that such excesses will be negative in the case of empty core. For the allocation obtained, if it is not a unique allocation, then have the obtained excesses fixed for every coalition whose dual variables are positive. Based on the fixed excess of the coalitions, for the rest of the coalitions, the smallest excesses are maximized. The procedure is repeated until we find one and only solution to the problem of LP. The one and only allocation is the so-called nucleolus.

3.4. Nash Bargaining Solution. The solution of Nash bargaining is a very powerful instrument when the negotiator interactions are modeled, and for bargaining games, it is one and only solution that meets the conditions of scale independence, symmetry, Pareto optimality, and independent irrelevant alternatives. According to past researches [25], the set including all individuals are denoted as $N = \{1, 2, \dots, n\}$, a vector of payoff refers to an factor of the payoff space R^N , and a feasible set S refers to a subset of the payoff space; a breakdown point \bar{b} refers to an factor of the payoff space. Therefore, the problem of bargaining problem can be specified as the triple (N, S, \bar{b}) . The solution is based on a function which is related to every bargaining problem (N, S, \bar{b}) , and it can be expressed as $F(N, S, \bar{b})$, where such a feasible set is convex and compact, it includes several vectors of payoff, and then every payoff of individual is higher than the breakdown payoff of the individual; in the case, the solution ensures that the four properties of Nash is unique, and it can be worked out by solving the problem of maximization as follows:

$$\text{Max} \prod_{i=1}^n (u_i - b_i), \quad (4)$$

where u_i refers to the payment vector of individual which is assigned by the cooperation and b_i refers to the independent payoff of individuals. Make sure that the income distributed is equal to the general income.

4. Leading-Idealism Cost Allocation Model (LiCAM)

4.1. Allocation Rule of Model. There is no single and all-purpose method to achieve cost allocation. The cooperative game theory provides a set of ideal attributes for the cost allocation method among a group of participants. When it comes to choose an existing method or developing a new method, we will look for a method that satisfies certain properties that are considered essential in our context. In the context of our cooperative organization, the allocation rules of the allocation model must satisfy five of these properties. First, the property of *efficiency* requires that the common cost of a coalition must be entirely split among its players. Second, the property of *coalition rationality* is the strongest stability condition and implies individual rationality and group rationality. The third property is a *reinforced individual rationality*: the ratio of cost allocated to NLC to coalition that include the NLC and LC should be less than the ratio of NLC’s independent cost to the NLC and LC total independent cost. Fourth, the *monotonic property* requires that the cost of a collaborating player does not increase with a new player to join in the alliance. We also propose a fifth property, called it *leader allocation advantage*, which is LC should be allocated less cost. Because under the centralized framework, the LC acts as a coordinator, and it has to bear more work and invests a lot of alliance establishment and management costs. So, in every coordinated transportation task, it should bear less operating costs. Some authors have studied the establishment cost and management cost in the literature on alliance formation, such as the connecting cost is used to study establishment cost of alliance by Slikker et al. [26] and Galeotti et al. [27]. While some other authors (e.g., Audy et al. [28]) use fixed unit costs to study the management cost.

4.2. Allocation Model. The formulation of LiCAM is in fact a multistage model. Let us take a look at the first stage. We build the following linear programming model to achieve x_i^* . The model is as follows:

$$P1: \max \sum_{i \in \text{NLC}} \frac{x_i}{c(\{i\})} - \sum_{i \in \text{LC}} \frac{x_i}{c(\{i\})}, \quad (5)$$

$$\text{s.t.} \sum_{i \in N} x_i = c(N), \quad (6)$$

$$\sum_{i \in S} x_i \leq c(S), \quad (7)$$

$$x_i \leq c(M) \times \frac{c(\{i\})}{\sum_{j \in M} c(\{j\})}, \quad i \in \text{NLC}, \quad (8)$$

$$x_i \geq 0. \quad (9)$$

Objective function (5) guarantees that LC is allocated less cost, and it corresponds to the *leader allocation advantage property*. Constraint (6) corresponds to the *efficiency*

condition, which states total cost should be completely allocated. Constraint (7) corresponds to the *coalition rationality* conditions. Constraint (8) demonstrates cost allocated to NLC is related to coalition M , and it corresponds to the *reinforced individual rationality*. Constraint (9) demonstrates that being a collaborating player in a coalition must bear a positive cost. By solving model $P1$, we can get the value of x_i , denoted as x_i^* .

The next step is the second stage. At this time, the alliance has new participants to join in. A new constraint must be added, that is the cost (y_i) of a collaborating player does not increase with a new player to join in the alliance. The new constraint (10) is as follows which corresponds to the *monotonic property*:

$$y_i \leq x_i^*, \quad i \in N. \quad (10)$$

This condition is too strict; many times, alliance leading company will be willing to sacrifice some benefits in exchange for other potential benefits (e.g., faster delivery time, to protect the company's market share and to broaden their services at the same time) and accept new members to join. Constraint (10) can be modified to the following constraint:

$$y_i \leq x_i^*, \quad i \in \text{NLC}. \quad (11)$$

These formulas can be generalized in the following way; at iteration $t+1$, solve the following linear program:

Model:

$$\max \sum_{i \in \text{NLC}_{t+1}} \frac{x_i^{t+1}}{c(\{i\})} - \sum_{i \in \text{LC}_{t+1}} \frac{x_i^{t+1}}{c(\{i\})}, \quad (12)$$

$$\text{s.t.} \sum_{i \in N_t} x_i^{t+1} = c(N_{t+1}), \quad (13)$$

$$\sum_{i \in S_{t+1}} x_i^{t+1} \leq c(S_{t+1}), \quad (14)$$

$$x_i^{t+1} \leq c(M_{t+1}) \times \frac{c(\{i\})}{\sum_{j \in M_{t+1}} c(\{j\})}, \quad i \in \text{NLC}_t, \quad (15)$$

$$x_i^{t+1} \leq x_i^*, \quad i \in \text{NLC}_t, \quad (16)$$

$$x_i^{t+1} \geq 0. \quad (17)$$

If constraint (16) is $x_i^{t+1} \leq x_i^*$, $i \in N_t$, the model is called the *strict model*. Model LiCAM is a linear programming model, which can be solved by many classical algorithms, such as simplex algorithm, ellipsoid method, and Karmarkar's algorithm. The specific algorithm to be selected is determined by the software. Relative indices, sets, parameters, and decision variables are illustrated in Table 1.

5. Computational Results

5.1. Case Description. The case study in this article is based on horizontal cooperation among freight carriers. A complete description of the case is found in Krajewska et al. [20]. They have generated three instances for five carriers. Each

carrier possesses one depot. The vehicle fleet is unlimited and homogenous for all carriers. The instances are different with regard to the number of requests that each carrier has to fulfill. For each instance, all 31 possible coalitions, consisting of one, two, three, four and five carriers, are assumed. Coalition S the minimum total cost is cited in Table 2.

In this section, we present the results of applying the allocation methods to the cases. We can evaluate the effect of each method and gain insight into the performance of method in practice. All results are calculated by Lingo11 using an Intel (R) Core (TM) i5-5200@2.20 GHz with 8 GB of RAM.

By comparison with classic methods such as the Shapley, nucleolus, and Nash bargaining solution, the aim is to demonstrate through simple and easily customized allocation rules how the Leading-idealism Cost Allocation Model can affect cost allocation among the collaborating players.

From Table 2, we further explain what the independent cost is and what the total independent cost is. The independent cost is the cost of participant to complete tasks independently. The total independent cost includes NLC's independent cost and LC's completion cost. For example, 5603.7 is the independent cost of participant A . 4156.9 is the independent cost of participant B . 4598.4 is the independent cost of participant C . If A is the LC and B is the NLC, then the total independent cost is (5603.7 + 4156.9) for the alliance $\{A, B\}$. If A is the LC, B is the LC, and C is the NLC, then the total independent cost is (8543.9 + 4598.4) for the alliance $\{A, B, C\}$.

5.2. Allocation Result Analysis. The allocation results of different coalition are calculated according to the methods of the Shapley, nucleolus, Nash, and LiCAM proposed by article as shown in Tables 3–5. Here, we assume that A is the leader of the alliance.

5.2.1. Computation Time. Among the four methods, the Nash method takes the longest time to calculate, and the main reason is that it is a nonlinear programming. The other three methods are very close. The average time of each method in the three cases is shown in Table 6.

5.2.2. Stability. Stable allocation is a concept from cooperative game theory. For such allocations, no subset of carriers has an incentive to withdraw from the collaborative planning on the basis of the allocation. As can be seen from the definition of LiCAM, their solutions satisfy efficiency condition corresponds to constraint (6) and coalition rationality condition corresponds to constraint (7). The core of game is the set of all vectors satisfying constraints (6) and (7). An allocation that belongs to the core is said to be stable. Therefore, the stability of LiCAM model is fully guaranteed in theory. In the same way, Nucleolus also guarantees its stability by definition, that is, their solutions satisfy individual rationality and coalition rationality. But, the Shapley value and Nash methods are not constructed by implicitly using any of the core criteria. Therefore, from a stability

TABLE 1: Indices, sets, parameters, and decision variables in the LiCAM.

Indices	
t	A stage in the coalition formation, with $t = 1, 2, \dots, NLC $
Sets	
N_t	The set of all players at stage t , $N_t = LC_t \cup NLC_t$
LC_t	The set of all leading player(s) at stage t
NLC_t	The set of all nonleading players at stage t
Parameters	
$C(N_t)$	Total cost is calculated by various multidepot optimization algorithms at stage t
$c(\{i\})$	The stand-alone cost of player i
$c(S_t)$	The cost of coalition S_t
$c(M_t)$	The cost of coalition M_t
S_t	The coalition that forms between players at stage t
M_t	The coalition that forms at stage t , where $M_t = LC_t \cup \{i_t\}$, $i \in NLC_t$
x_i^t	The calculated cost value of player i by model P1
Decision variable	
x_i^t	Cost of player i allocated by alliance at stage t

TABLE 2: Coalition S the minimum total cost quoted from article Krajewska et al. [20].

Carriers in coalition S	T1	T2	T3
A	5603.7	7468.5	5603.7
B	4156.9	6390.7	5890.6
C	4598.4	7275.9	7275.9
D	5406.9	7518.7	5406.9
E	5236.9	7202.9	6492.2
A B	8543.9	11638.8	9346.6
A C	8433.8	12825.7	11223.9
A D	9836.6	14236.7	9836.6
A E	9490.3	13031.4	10383.1
B C	7780	11785.7	11144.1
B D	8943.1	12884.1	10537.1
B E	8362.4	12053	10138.8
C D	8488.4	13050.3	11012.8
C E	9004.5	13771.7	13066.1
D E	10028.2	14649.1	11217.6
A B C	11588.4	16910.3	14774.5
A B D	12394.6	17847.8	13179.9
A B E	12338.1	17034.7	13971.3
A C D	12485.4	18807.9	14984.3
A C E	12671.6	18543.9	16446.3
A D E	13827.4	19763.9	15181.5
B C D	11281.1	16989.8	14628.7
B C E	11879.7	17681.8	16335.2
B D E	13205.6	18489.2	15125.6
C D E	12910.1	19450.2	16768.8
A B C D	15238.4	22731.6	18775.3
A B C E	15262.8	22738.7	19755.4
A B D E	16587.3	23298.3	18276.5
A B D E	16573.2	24597.4	20337.8
B C D E	15427.8	22830.9	19774.6
A B C D E	18927.1	28005.3	23443.5

point of view, the Shapley value and Nash methods performs worst. However, for each instance in Tables 3–5, all four mechanisms develop a cost allocation that stays at the core.

5.2.3. Consistency with the Leader Allocation Advantage Property. In order to determine the consistency with the principle that the leading company's cost allocation is as small

TABLE 3: Allocation results of T1.

Coalition	Shapley	Nucleolus	Nash	LiCAM
Grand coalition $N = \{A, B\}$				
{A}	4995.4	4995.4	4995.4	4905.2
{B}	3548.5	3548.5	3548.5	3638.7
Grand coalition $N = \{A, B, C\}$				
{A}	4507.8	4348.3	4680.2	4148.3
{B}	3457.5	3655.8	3233.4	3638.7
{C}	3623.2	3584.4	3674.9	3801.4
Grand coalition $N = \{A, B, C, D\}$				
{A}	4382.7	4465.9	4471.8	3957.3
{B}	3241.1	3261.6	3025.0	3638.7
{C}	3324.4	3352.4	3466.5	3801.4
{D}	4290.3	4158.6	4275.0	3841.0
Grand coalition $N = \{A, B, C, D, E\}$				
{A}	4142.1	4175.5	4388.6	3499.3
{B}	3052.1	3030.1	2941.8	3638.7
{C}	3177.0	3016.0	3383.3	3801.4
{D}	4282.5	4340.5	4191.8	3664.3
{E}	4273.4	4364.9	4021.8	4323.4

as possible, the calculation results are analyzed. In cases 1 and 2, as the number of alliance members continues to increase, it can be seen that the cost of leading company A calculated by LiCAM method is allocated the smallest cost in each phase of the alliance. In case 3, only in the case of {AB} coalition, the cost allocated to leading company A calculated by LiCAM method is a little more than that of the other methods.

We use the following method to calculate average consistency. The consistency is divided into 4 levels, which are scored 1, 2, 3, and 4, respectively. The lowest cost allocation method for leading company A is 4 points, the second lowest is 3 points, and the highest is 1 point. The calculation formula is as follows:

$$\text{Average Consistency} = \frac{\sum \sum P_{\text{method}}}{|C| \times |S_c|}, \quad (18)$$

TABLE 4: Allocation results of T2.

Coalition	Shapley	Nucleolus	Nash	LiCAM
Grand coalition $N = \{A, B\}$				
{A}	6358.3	6358.3	6358.3	6271.9
{B}	5280.5	5280.5	5280.5	5366.8
Grand coalition $N = \{A, B, C\}$				
{A}	5997.3	5934.5	6060.2	5214.4
{B}	4938.4	4894.5	4982.4	5366.8
{C}	5974.5	6081.4	5867.6	6329.1
Grand coalition $N = \{A, B, C, D\}$				
{A}	6082.7	6332.0	5988.0	5741.8
{B}	4718.7	4513.9	4910.2	5366.8
{C}	5559.3	5474.0	5795.4	5801.7
{D}	6370.9	6411.6	6038.2	5821.3
Grand coalition $N = \{A, B, C, D, E\}$				
{A}	5757.4	5969.1	5898.2	5174.4
{B}	4435.8	4202.6	4820.4	5366.8
{C}	5523.7	5602.8	5705.6	5799.8
{D}	6253.6	6162.4	5948.4	5266.6
{E}	6034.8	6068.4	5632.6	6397.7

TABLE 5: Allocation results of T3.

Coalition	Shapley	Nucleolus	Nash	LiCAM
Grand coalition $N = \{A, B\}$				
{A}	4529.9	4529.9	4529.9	4556.7
{B}	4816.8	4816.8	4816.8	4789.9
Grand coalition $N = \{A, B, C\}$				
{A}	4312.0	4352.3	4271.8	3644.0
{B}	4415.6	4272.5	4558.7	4789.9
{C}	6046.9	6149.8	5944.0	6340.5
Grand coalition $N = \{A, B, C, D\}$				
{A}	4382.7	4465.9	4253.3	4146.6
{B}	3241.1	3261.6	4540.2	4202.9
{C}	3324.4	3352.4	5925.5	5595.4
{D}	4290.3	4158.6	4056.5	4830.4
Grand coalition $N = \{A, B, C, D, E\}$				
{A}	4069.2	4283.3	4158.5	3668.9
{B}	3987.9	3721.5	4445.4	4202.9
{C}	5783.1	5782.8	5830.7	5167.0
{D}	4286.8	4303.9	3961.7	4830.4
{E}	5316.6	5352.2	5047.1	5572.9

TABLE 6: Computation time.

Method	Shapley	Nucleolus	Nash	LiCAM
Average (s)	<0.05	<0.05	15	<0.05

where p_{method} is the consistency score obtained by the same method in every coalition in the case, $|C|$ is the number of cases, and $|S_c|$ is the number of coalitions generated in the case. According to the above method, it can be seen that the average consistency of LiCAM is the highest. In terms of frequency, the consistency illustrates the probability that the

TABLE 7: Consistency with the leader allocation advantage property.

Method	Shapley	Nucleolus	Nash	LiCAM
Average consistency (%)	64.58	52.08	58.33	97.92

LiCAM method will allow leading companies to be allocated less cost. The specific results are shown in Table 7.

5.2.4. *The Value of Being a Leading Company.* From the perspective of individual participants, the value of being an alliance leader is obvious. We do the following test. In the ABCDE Alliance of Case 1, company B will save up to 35.31% if company B as the leader, which also reflects the protection of the leader’s interests by this method. The allocation results are shown in Table 8.

From a holistic perspective, the value of being a leader can be reflected in the LiCAM method. In case 1, the Nash method has the highest cost allocation to leading company A, and the nucleolus method has the lowest. LiCAM saves 11.23% on average compared with the Nash method. It also saved an average of 8.21% compared with the nucleolus method. In Case 2, the nucleolus method allocated the highest cost to leading company A, and the Shapley method has the lowest. LiCAM saved 8.97% on average compared with the nucleolus method. It also saved an average of 7.36% compared with the Shapley method. In case 3, the nucleolus method has the highest cost allocation to the leading company A, and the Nash method has the lowest. LiCAM saves 9.29% on average compared with the nucleolus method and also saves 6.91% on average compared with the Nash method. In terms of quantity, the value of being a leading company reflects how much LiCAM can let leading companies allocate cost value less than other methods. Table 9 illustrates the average of the various methods in the three cases.

5.2.5. *The Number of Leading Companies.* The above discussion is all about the situation where there is only one leader in the alliance. What if there are two, three, and four leaders in the alliance? Choose {A}, {A, B}, {A, B, C}, and {A, B, C, D} as the leaders in three cases, and the calculation results are shown in Tables 10–12.

When the number of leaders increases, in fact, the cost allocation of the original leader will be more than the original level. There is a conflict of interest. Why did the original leader need a new leader to join in? Although cost reduction is usually by far the most important of the potential benefits, a question still remains: what payoff is required to incite a player to collaborate? In practice, this issue is much more complex. There exist several other potential benefits (e.g., faster delivery time, to protect the company’s market share and to broaden their services at the same time) than cost reduction to perform horizontal cooperation in transportation and logistics. Several opportunities and advantages to horizontal cooperation are also detailed in the literature review of Cruijssen et al. [22]. An added benefit of horizontal cooperation is that not only cost savings can be obtained but also CO₂ emissions can be reduced (e.g., Ballot and Fontane [29]).

TABLE 8: The value of being a leading company for company *B* in the *ABCDE* alliance of *T1*.

Allocation	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
Company <i>A</i> as leader	3499.3	3638.7	3801.4	3664.3	4323.4
Company <i>B</i> as leader	3663.1	2353.9	4086.2	4162.0	4661.9

TABLE 9: Comparison of different methods of value as a leading company.

Value of being a player	<i>T1</i> (%)	<i>T2</i> (%)	<i>T3</i> (%)
Shapley	97.18	97.87	97.91
Nucleolus	96.98	99.48	99.85
Nash	100.00	98.34	97.47
LiCAM	88.77	90.51	90.56

TABLE 10: Cost allocation results for multiple leading companies in the alliance (*T1*).

Allocation	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
Company <i>A</i> as the leader	3499.3	3638.7	3801.4	3664.3	4323.4
Companies <i>A</i> and <i>B</i> as the leaders	3663.1	2353.9	4054.7	4166.7	4688.7
Companies <i>A</i> , <i>B</i> , and <i>C</i> as the leaders	4228.9	2353.9	2745.8	4847.9	4750.6
Companies <i>A</i> , <i>B</i> , <i>C</i> , and <i>D</i> as the leaders	4649.4	2353.9	2745.8	4337.1	4840.9

TABLE 11: Cost allocation results for multiple leading companies in the alliance (*T2*).

Allocation	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
Company <i>A</i> as the leader	5174.4	5366.8	5799.8	5266.6	6397.7
Companies <i>A</i> and <i>B</i> as the leaders	5174.4	3407.9	6504.9	6406.0	6512.1
Companies <i>A</i> , <i>B</i> and <i>C</i> as the leaders	5975.3	3407.9	4833.5	6996.3	6792.3
Company <i>A</i> , <i>B</i> , <i>C</i> , and <i>D</i> as the leaders	5506.5	3407.9	4833.5	7518.7	6738.7

TABLE 12: Cost allocation results for multiple leading companies in the alliance (*T3*).

Allocation	<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
Company <i>A</i> as the leader	3668.9	4202.9	5167.0	4830.4	5572.9
Companies <i>A</i> and <i>B</i> as the leaders	3668.9	3105.7	6111.9	4830.2	5726.7
Companies <i>A</i> , <i>B</i> , and <i>C</i> as the leaders	3668.9	3105.7	5607.9	5030.2	6030.8
Companies <i>A</i> , <i>B</i> , <i>C</i> , and <i>D</i> as the leaders	3668.9	3309.1	6753.9	3688.1	6023.5

5.2.6. *Size of Grand Coalition.* The interesting result is that adding more partners to the collaboration will reduce the revenue [6]. The Shapley method and Nucleolus method prove this. When the number of participants increases, it may cause the cost of the existing alliance members to be allocated lower than the cost of the new alliance. This will

TABLE 13: The number of companies in grand coalition.

Coalition	Method											
	Shapley			Nucleolus			Nash			LiCAM		
	<i>T1</i>	<i>T2</i>	<i>T3</i>									
Two participants	√	√	√	√	√	√	√	√	√	√	√	√
Three participants	√	√	√	×	√	√	√	√	√	√	√	√
Four participants	√	√	√	√	√	√	√	√	√	√	√	√
Five participants	√	√	×	×	×	×	√	√	√	√	√	√

TABLE 14: The number of companies in grand coalition in the *strict model*.

Coalition	Method											
	Shapley			Nucleolus			Nash			LiCAM		
	<i>T1</i>	<i>T2</i>	<i>T3</i>									
Two participants	√	√	√	√	√	√	√	√	√	√	√	√
Three participants	√	√	√	×	√	√	√	√	√	√	√	√
Four participants	√	×	×	×	×	×	√	√	√	√	×	×
Five participants	√	√	×	×	×	×	√	√	√	√	√	√

cause alliance members to resist new members joining. In fact, this goes against the monotonic property discussed in Section 4.1. But, both the Nash method and the LiCAM method ensure that the cost allocated to members by the new larger alliance is still equal to or less than the cost allocated to the original alliance as the members increase. The original members of the alliance will not resist the joining of new members. The analysis results are shown in Table 13.

If we use the *strict model*, the results are shown in Table 14. Although the LiCAM method has increased the cost of leaders as new members joined, it must be seen that the initial cost is much lower than other methods. Even if the cost of the leader increases, it is still much lower than the cost allocated by other methods.

From the calculation results, although the later members can be guaranteed to be less than their own independent costs, they will undoubtedly be allocated more costs by the alliance. This is also in line with the actual situation. When the members can no longer obtain less than their own independent costs from the alliance, the alliance members reach the upper limit.

6. Conclusion

In this paper, we consider the cost allocation in horizontal logistic transportation planning. Five fairness criteria are introduced in this specific context. And, based on these criteria, we propose the Leading-idealism Cost Allocation Model. In our case study, the calculation time of LiCAM is as good as that of Shapley and Nucleolus, and the Nash method performs worst. In consistent with leader

allocation advantage property, LiCAM performs best, which is 33.34%–45.84% higher than that of the other methods. The value of alliance leaders is fully respected, reflecting the balance of interests and responsibilities. Further, we analyzed the number of leaders in the alliance. Calculation shows that too many leaders in the alliance will weaken the distribution of leaders' interests. Finally, we analyzed the size of the alliance. When the members can no longer obtain less than their own independent costs from the alliance, the alliance members reach the upper limit. Our proposed method ensures that the alliance remains stable as the size of the alliance increases. But, the Shapley and Nucleolus methods are not.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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