Research on the Profit Distribution Model of the Rail-Road Intermodal Transport Alliance Based on Improved Cloud Center of Gravity-Shapley Value

Haoyu Ru

{815179393@qq.com}

Institute of Logistics Science and Engineering, Shanghai Maritime University, Shanghai, China

Abstract. A reasonable profit distribution scheme is crucial for the sustained cooperation among enterprises within the rail-road intermodal transport alliance, serving as the foundation for the stable operation of the alliance. Therefore, this study deeply explores the main factors affecting the profit distribution of the rail-road intermodal transport alliance and employs an improved cloud center of gravity method to calculate the weights of enterprises. Consequently, a profit distribution model based on the improved cloud center of gravity-Shapley value is constructed, and its effectiveness is verified through numerical simulation. The results indicate that the improved model yields a more fair and reasonable distribution scheme, which aligns more closely with practical situations, facilitating the stability and efficient operation of the alliance.

Keywords: Rail-road intermodal transport alliance; Shapley value; Profit distribution;

1 Introduction

The rail-road intermodal transport alliance refers to an alliance organization formed through the cooperation of operators, road enterprises, and railway enterprises, aimed at enhancing transportation efficiency and reducing transportation costs. However, the establishment and stable operation of such alliances face numerous challenges, particularly in profit distribution. Unreasonable profit distribution can lead to conflicts of interest among members and even the dissolution of the alliance, making it imperative to design a scientific and rational profit distribution scheme.

Current scholars have explored various methods and influencing factors of profit distribution. Li et al. (2022) found that the status of the alliance and transportation resources are key factors in profit distribution, and modified the Raiffa solution based on the coefficient of variation method and the analytic hierarchy process[1]. Jia et al. (2023) constructed an ant colony labor model for profit distribution[2]. Duan et al. (2022) used the Myerson value method to distribute profits in sea-rail intermodal transport alliances. Against the backdrop of multimodal transportation systems and platforms[3]. Deng et al. (2022) designed a profit distribution scheme based on an asymmetric Nash bargaining solution[4]. Encarnación et al. (2018) proposed two profit distribution methods based on game theory to prevent companies from exiting the alliance and achieve a rational distribution of profits. Many scholars have also modified the traditional Shapley value method based on the influencing factors of profit

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distribution, for example[5]. Zhu et al. (2022) considered time windows, risk, and penalty factors[6]. He et al. (2023) took into account effort level and enterprise positioning[7]. Guo et al. (2021) considered task volume and customer satisfaction[8]. Yu et al. (2018) looked at leadership, market influence, and participation willingness[9]. Luo et al. (2017) considered contract execution, contribution degree, and investment proportion[10]. Qi et al. (2015) factored in innovation execution and extra contributions[11].

Through analysis, it is clear that current research considers various factors and employs different methods, but has not focused on the rail-road intermodal transport alliance. Therefore, this paper combines the characteristics of the rail-road intermodal transport alliance, considering four factors: resource input, risk assumption, effort level, and corporate status, to propose a profit distribution model based on the improved cloud center of gravity-Shapley value. This model aims to achieve a more reasonable distribution scheme, ensuring the stability of the rail-road intermodal transport alliance and promoting the development of rail-road intermodal transport

2 Analysis of Factors Affecting Profit Distribution in the Rail-Road Intermodal Transport Alliance

This paper, through an in-depth analysis of existing literature and considering the characteristics of rail-road intermodal transport, summarizes four key factors affecting profit distribution within the rail-road intermodal transport alliance.

2.1 Resource Input

Resource input is the foundation for the normal operation and development of the rail-road intermodal transport alliance, mainly including equipment, manpower, and financial resources. Resource input not only reflects the role and value of enterprises within the alliance but also relates to their contributions. To ensure the smooth operation of the rail-road intermodal transport alliance, it is necessary to provide a reasonable profit return on the resource costs invested by all members, adhering to the principle that input matches distribution. Otherwise, it may lead to the withdrawal of enterprises whose interests are damaged, resulting in the disbandment of the alliance.

2.2 Risk Bearing

The operation of the rail-road intermodal transport alliance inevitably faces various risks, including market environment changes, policy adjustments, personnel management, and technical challenges. These risks can affect the profits of enterprises and threaten the stability of the alliance. Therefore, it is essential to reasonably assess the risks undertaken by each enterprise, ensuring that risk bearing matches profit, thereby stimulating enterprises' enthusiasm to participate in cooperation and providing a guarantee for the long-term stable development of the alliance.

2.3 Effort Level

Within the alliance, enterprises often seek to maximize their own profits and operate their other businesses while providing rail-road intermodal transport services. This leads to varying levels of effort, which can have either positive or negative impacts on the alliance. These effort levels are mainly reflected in marketing, service quality, and the degree of cooperation. Therefore,when formulating distribution schemes, it is important to fully consider the activeness of each enterprise's participation in the alliance, thereby motivating them to improve their effort levels and promote the stable and efficient operation of the alliance.

2.4 Corporate Status

In the rail-road intermodal transport alliance, the status of member enterprises not only determines their say within the alliance but also reflects their importance to the alliance. Factors affecting corporate status mainly include market share, replaceability, and business growth rate. The higher the status of a member, the more opportunities and resources it brings, benefiting the profit growth and development of the alliance and positively influencing other enterprises. Therefore, in profit distribution, it is crucial to fully consider the status of members, making it an important indicator for profit distribution to prevent free-riding behavior and ensure the fairness of profit distribution.

3 Improved Cloud Center of Gravity-Shapley Value Profit Distribution Model

3.1 Traditional Shapley Value Model

The Shapley value method calculates the profit allocated to each member based on the marginal contribution of the members joining the alliance. Specifically: assume an alliance is composed of n members, represented as a set $N = \{1, 2, \cdots, n\}$, and any formed sub-alliance is denoted as S, with the profit obtained by this sub-alliance represented by $V(S)$. $V(S)$ needs to satisfy the condition that participating in the cooperation yields higher profits. The profit $\varphi(v)$ distributed to each member can be calculated using the following formula:

$$\varphi_i(v) = \sum_{S \subseteq S_i} \frac{(n - |S|)!\,(|S| - 1)!}{n!} [V(S) - V(S/i)] \tag{1}$$

where $V(S - i)$ is the profit of alliance S after removing firm i, $|S|$ is the number of firms in alliance S.

3.2 Revised Weight Calculation

The cloud center of gravity method, developed from cloud theory, is an evaluation method that facilitates the conversion between qualitative and quantitative relationships. It is characterized by three numerical features: expectation (Ex), entropy (Ex), and hyper-entropy (He). The cloud center of gravity can be expressed as: $T = a * b$, where a represents the position of the cloud's center of gravity, i.e., Ex, and b denotes the height of the cloud's center of gravity, i.e., the weight of the influencing factors. Due to the cloud center of gravity model's lack of non-negativity, additivity, and normalization in the measurement of weighted deviation, this paper applies the TOPSIS method to refine the cloud center of gravity with the following steps:

(1) Represent each factor with a cloud model. Invite a diversified panel of experts to score the enterprises and select m scoring sheets with high similarity in scores to obtain m precise values $E_{x1} \sim E_{xm}$. The digital characteristics of the cloud model are $E_x = \frac{(E_{x1}+E_{x2}+\cdots+E_{xm})}{m}$, $E_n = \frac{Max\{E_{x1},E_{x2},\cdots,E_{xm}\}-Min\{E_{x1},E_{x2},\cdots,E_{xm}\}}{6}$.

(2) Construction of a four-dimensional comprehensive cloud. Based on the expert ratings of four factor indicators, a four-dimensional comprehensive cloud is established, represented by the vector $T = (T_1, T_2, T_3, T_4)$, where $T_k = a_k * b_k$; a_k denotes the expected value of indicator k, and b_k denotes the weight of indicator k.

(3) Determination of weights for each factor indicator. Based on knowledge of queue theory, the weights of factor indicators are determined using the following formula:

$$w_i = \begin{cases} \frac{1}{2} + \frac{\sqrt{-2ln\,(\frac{i-1}{p})}}{6}, & 1 < i \leq \frac{p+1}{2} \\ \frac{1}{2} - \frac{\sqrt{-2ln\,(2-\frac{2(i-1)}{p})}}{6}, & \frac{p+1}{2} < i \leq p \end{cases} \tag{2}$$

(4)Calculation of distance between the cloud center of gravity and the positive-negative ideal states based on TOPSIS. The composite cloud center of gravity and the positive-negative ideal composite cloud center of gravity position vectors are $E^{+(-)} = (E_1^{+(-)}, E_2^{+(-)}, E_3^{+(-)}, E_4^{+(-)})$, with height $b = (w_1^*, w_2^*, w_3^*, w_4^*)$, and the cloud center of gravity vector is $T^{+(-)} = (T_1^{+(-)}, T_2^{+(-)}, T_3^{+(-)}, T_4^{+(-)})$. The distance from T to $T^{+(-)}$ is calculated as $d^{+(-)} = \sqrt{\sum_{i=1}^{4}(T_i - T_i^{+(-)})^2}$.

(5)Calculation of enterprise weights. First, calculate the relative closeness degree of the comprehensive cloud center of gravity to the ideal state cloud center of gravity $\xi_i = \frac{d_i^-}{d_i^- + d_i^-}$, then normalize it to obtain the weights of profit distribution for enterprises within the alliance θ_i.

3.3 Improved Cloud Center of Gravity-Shapley Value Model

The weight calculation results mentioned above are introduced to refine the traditional Shapley value model outcomes, obtaining the final profit value for enterprise $\varphi_i(v)^*$.

$$\varphi_i(v)^* = \varphi_i(v) + \varphi(V) * (\theta_i - \frac{1}{n}) \tag{3}$$

4 Numerical Analysis

To validate the effectiveness of the model, the following text will simulate numerical examples before and after the improvement of the Shapley value model and analyze the results. Suppose a rail-road intermodal transport alliance consists of three enterprises, with enterprise numbers $i = 1,2,3$. The profits obtained by each enterprise operating independently are 10 thousand dollars, 25 thousand dollars, and 50 thousand dollars, respectively; the profits of alliances {1,2}, {1,3}, {2,3}, and {1,2,3} are 55 thousand dollars, 75 thousand dollars, 100 thousand dollars, and 140 thousand dollars, respectively.

4.1 Profit Distribution with the Traditional Shapley Value Model

When solving the alliance's profit distribution scheme using the traditional Shapley value model, the profit distribution values for each enterprise are calculated using the formula in section 3.1, with the results shown in Table 1.

Table 1. Traditional Model Profit Distribution Scheme

Enterprise	Enterprise 1	Enterprise 2	Enterprise 3
$\varphi_i(v)$ (thousand dollars)	25.83	45.83	68.33

4.2 Profit Distribution with the Improved Cloud Center of Gravity-Shapley Value Model

Invite a diversified expert panel consisting of industry experts, financial experts, performance experts, entrepreneurs, and academic professors to score Enterprise 1. Filter and retain 5 questionnaires with high scoring similarity and calculate the Ex and En for each indicator. The positive and negative ideal values are set as 0 and 1, respectively. At the same time, calculate the weight of each indicator according to formula (2), as shown in Table 2.

Table 2. Scores, E_x, E_n, and W_i^* for Each Indicator of Enterprise 1

Influencing Factors	Resource Input	Risk Bearing	Effort Level	Corporate Status
Expert 1	0.35	0.37	0.67	0.31
Expert 2	0.38	0.47	0.59	0.34
Expert 3	0.42	0.26	0.64	0.31
Expert 4	0.3	0.42	0.68	0.32
Expert 5	0.32	0.46	0.64	0.27
Ex	0.354	0.396	0.644	0.31
En	0.02	0.035	0.015	0.0117
Rank	1	3	2	4
w_i	1	0.3038	0.6962	0.5
w_i^*	0.4	0.1215	0.2785	0.2

Based on the data from Table 1 and Table 2, the comprehensive cloud vector for Enterprise 1 is calculated as $T = (0.14,0.04,0.18,0.06)$, with the positive and negative ideal state cloud centers of gravity $T^+ = (0.4,0.12,0.28,0.2)$ and $T^- = (0,0,0,0)$, respectively. The distances from T to T^+ and T^- are d^+ and d^-, respectively, measuring 0.32 and 0.24. with the relative closeness degree ξ_1 of 0.43. Similarly, the relative closeness degrees ξ_2 and ξ_3 for Enterprises 2 and 3 are calculated as 0.53 and 0.57, respectively. Following this, ξ_i is normalized to obtain the weight θ_i for each enterprise, and the profits allocated to each enterprise are calculated according to formula (4), with the results shown in Table 3.

Table 3. Improved Model Profit Distribution Scheme

Enterprise	Enterprise 1	Enterprise 2	Enterprise 3
ξ_i	0.43	0.53	0.57
θ_i	0.28	0.35	0.37
$\varphi_i(v)^*$(thousand dollars)	18.41	47.73	73.86

4.3 Comparative Analysis

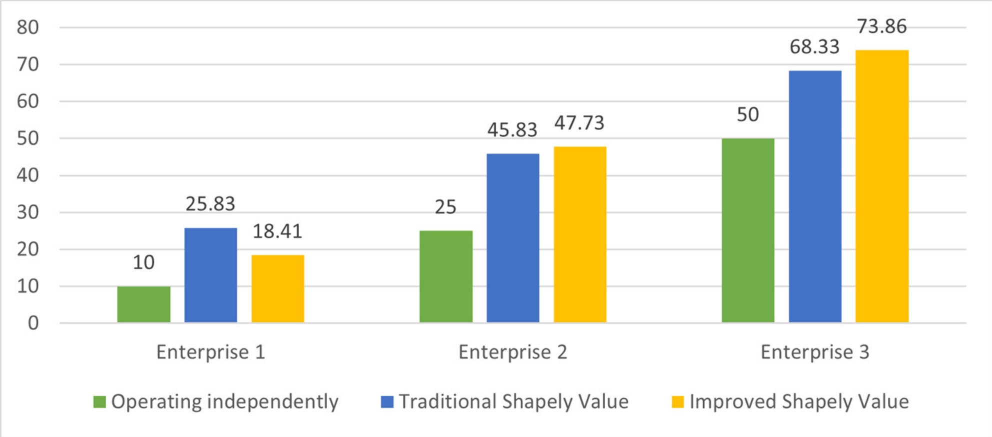

Fig. 1. Rail-Road Intermodal Transport Alliance Profit Distribution Scheme

By comparing the profit distribution schemes before and after the improvement of the Shapley value for enterprises operating independently and forming a cooperative alliance, as shown in Figure 1, it can be observed that the profits of each enterprise have changed. The following conclusions can be drawn:

(1)Regardless of the profit distribution model used, all enterprises in the cooperative alliance achieve higher profits than when operating independently. This is because the alliance often makes decisions aimed at maximizing the alliance's profits, reducing the losses caused by the "multi-marginal effects" to the alliance.

(2)In the improved distribution scheme, the profits of the road and railway enterprises have increased, while the profits of the operators have decreased. This is due to the fact that road and railway enterprises have invested more resources and borne greater risks.

(3)In the improved distribution scheme, the increase in profits for the railway enterprise is more significant. This is because the railway transportation services it provides are irreplaceable, and it plays a more critical role and holds a higher status within the alliance.

5 Conclusion

A reasonable profit distribution scheme is key to ensuring stable cooperation and long-term development among members of the rail-road intermodal transport alliance. Unreasonable profit distribution may lead to tensions or even breakdowns in the cooperation among members. The Shapley value, due to its simplicity of operation, has been widely applied to profit distribution issues in various alliances. However, the Shapley value only considers the marginal contribution of enterprises in the profit distribution process, ignoring the impact of other factors on distribution. Therefore, to ensure a better profit distribution scheme, this paper considers four influencing factors: resource input, risk assumption, effort level, and member status, resulting in a profit distribution model based on the improved cloud center of gravity-Shapley value. To avoid the subjectivity of scoring by experts from a single field, this paper invites a panel of experts consisting of industry experts, financial experts, performance experts, entrepreneurs, and academic professors to score each enterprise in the alliance, selecting and retaining questionnaires with high scoring similarity as data support. To ensure the scientific validity and effectiveness of the model, this paper also conducts numerical simulations and comparative analysis. It is found that the improved profit distribution model can achieve a more scientific and reasonable profit distribution scheme, ensuring that profits match risks and inputs, which is conducive to stimulating the cooperative enthusiasm of alliance members and facilitating the development of the rail-road intermodal transport alliance.

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