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Benefit Evaluation of Joint Distribution based on DEA Model

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Abstract. The logistics industry has gradually developed into a pillar industry in the city, which drives the development of urban economy. However, the economic and environmental problems caused by the rapid development have become increasingly prominent. As an important way to alleviate these problems, joint distribution has gradually moved from theory to implementation. Based on DEA model, the paper calculates the changes of enterprise income and carbon emissions before and after joint distribution, establishes a comprehensive evaluation system covering economic output and environmental impact output, calculates the input-output efficiency of the two efficiency, and comprehensively evaluates the impact of joint distribution on urban logistics. The results show that the economic and environmental benefits of joint distribution are significantly better than that of individual distribution. Joint distribution has significant advantages in reducing costs and improving environment.

Keywords: joint distribution, DEA mode, economic benefit, environmental benefit, benefit evaluation component

1. Introduction

The concept of joint distribution was first put forward in Japan. Yazawa first studied the joint distribution among enterprises in the same industry from the perspective of academic research in 1973, and published an article in 1975, emphasizing that the main issues faced by joint distribution are "conservatism of business leaders' sense of operation" and "integration of logistics to promote the main functions and reasonable freight burden system" This is the earliest known literature on joint distribution from an academic perspective [1].

The research of early scholars mainly took joint distribution as a strategic direction to carry out feasibility study. Xu Q (2004) systematically analyzed the characteristics of logistics collaboration at all levels of regional logistics system link enterprise supply chain industry [2]. Around 2010, the research on joint distribution mechanism gradually increased, mainly focusing on the vertical joint collaboration of goods transportation, and Yan Fei and Dong Q (2009) analyzed the point-to-point collaboration, line to line collaboration, point to line collaboration and chain to chain collaboration, and analyzed the mechanism of node enterprise collaboration based on the synergetic theory [3]. In the following years, most of the related researches integrated enterprises from the perspective of supply chain. Wang Y et al. (2017,2018) considered the establishment of a two-level joint logistics joint distribution network cooperation and sharing alliance, and established a linear optimization model of logistics facility allocation and a linear mathematical model that can explain the real world practice under single or multiple alliance schemes [4,5].

In recent years, China's urbanization process is speeding up, and the scale of cities is expanding. In order to solve the traffic congestion and environmental deterioration caused by the large number of commercial and pedestrian flows in the city, various places have introduced traffic control measures to restrict trucks entering the city, such as the truck pass into the city, limited time, etc., These measures have a great impact on the city logistics distribution, leading to the problems of "the last kilometer" vehicles entering the city and high cost. At the same time, the rapid development of e-commerce in China, the rapid change of circulation mode and the improvement of consumers' attention to food quality and safety have put forward new requirements for the organization mode of logistics distribution. In this context, joint distribution is getting

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more and more attention from government departments and industry, and from theoretical exploration to specific implementation stage.

At present, the research of collaborative distribution at home and abroad focuses on the concept and connotation of joint distribution (Ferrell W, 2019) [6], joint distribution benefit (Liu G et al, 2020; Melkonyan A et al, 2020; Bi K et al, 2020) [7,8,9], joint distribution mode (Zhang X et al., 2013; Yang M et al., 2015) [10,11], joint distribution benefit distribution and cost sharing (Hong S et al., 2018; Zhao X et al., 2019; Wang D et al., 2019) [12,13,14].The benefit evaluation of joint distribution has become a hot issue. What is the effect of joint distribution? How to improve and promote the logistics performance of urban joint distribution? To solve these problems, the primary task is to evaluate the benefits of joint distribution. Many scholars use different methods to evaluate the benefit of joint distribution. Liu G et al (2020) established a joint distribution green vehicle routing problem (JD-GVRP) model, optimized the model with simulated annealing algorithm, linked cold chain logistics with joint distribution and carbon trading mechanism, and evaluated the economic and environmental benefits of cold chain logistics[7]. Melkonyan A et al(2020)developed a set of tools to explore the sustainable development potential of last mile logistics and distribution strategy, and used system dynamics (SD) simulation and multi criteria decision assist (MCDA) methods to evaluate the sustainability performance of distribution channel schemes [8].Bi K et al(2020)proposed a new collaborative distribution mode based on intelligent terminal service station . Based on the carbon emission measurement model, the carbon emission measurement model before and after cooperative allocation is given, and the environmental benefits of the new model are verified [9].

There are a lot of literatures using DEA model to analyze logistics, but they mainly focus on evaluating the efficiency of enterprise logistics system, or as a basis for selecting logistics service providers, or to evaluate the effectiveness of input-output of Chinese cities. Manuel C (2013) started from the application of data envelopment analysis (DEA) nonparametric technology, and studied the factors influencing the distribution efficiency of the company by analyzing the process of large-scale distribution channel [15],Gong X et al. (2019) used DEA Malmquist index model to evaluate the input-output efficiency of logistics industry in 31 provinces (autonomous regions, cities) of China from the aspects of comprehensive efficiency, pure technical efficiency and scale efficiency [16], Shi C et al. (2010) set the evaluation results of cross model as the expected value of samples, organically combined BP neural network and cross evaluation model, and constructed the logistics supplier selection model [17],Wang M (2019) proposed a super efficiency DEA model for supplier evaluation with unexpected output in fuzzy environment based on the comparison rules of fuzzy numbers, which effectively solved the problem of total ranking of suppliers with unexpected output in fuzzy environment [18], Xu J et al. (2013) took 12 prefecture level cities in Gansu Province as research samples, constructed the evaluation index system of urban efficiency, and used DEA cross evaluation model to study the efficiency of these 12 cities in 2005 and 2009. At the same time, virtual decision-making units are introduced to further clarify the potential of efficiency improvement in each city [19].

At present, the research on the evaluation of the benefits of joint distribution is very few by using the data envelopment analysis method. This paper draws on the research results of other scholars on urban logistics evaluation index system, and considers the comprehensiveness and availability of indicators, constructs a multi input and single output index system of joint distribution benefit evaluation based on DEA analysis， and calculates the application of joint distribution index data according to historical data and theoretical knowledge. According to the envelopment analysis (DEA) method, this paper evaluates the joint distribution benefits of express enterprises in Haidian District of Beijing, and quantitatively analyzes the differences of input-output efficiency of express enterprises and their reasons, so as to provide basis for better urban logistics planning. This template, modified in MS Word 2007 and saved as a “Word 97-2003 Document” for the PC, provides authors with most of the formatting specifications needed for preparing electronic versions of their papers. All standard paper components have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

2. Joint Distribution Model Based on DEA

2.1. Model introduction

Data envelopment analysis (DEA) is a new system analysis method developed by famous American operational research experts A.Charnes and W.W.Cooper on the basis of "relative efficiency evaluation" [20].

In the theoretical system of DEA, the most representative evaluation models are CCR model and BCC model. The former is used to evaluate the overall effectiveness of scale efficiency and pure technical efficiency of decision-making units (total effective value = scale efficiency * pure technical efficiency), while the latter can be used to evaluate pure technical efficiency of decision-making units.

2.2. Model building

Data envelopment analysis (DEA) refers to an economic system (or person) that can input a certain number of production factors and produce a certain number of products through a series of decisions as decision making units (DMU). There are n express delivery enterprises (decision-making units), each enterprise (DMU) participating in distribution has m types of input indicators X and s types of output indicators y, the input of DMU_j is $X_j=(x_{1j},\cdots,x_{mj})^T$, The output is $Y_j=(y_{1j},\cdots.y_{sj})^T$, The weight vector of input index $V=(v_1,\cdots v_m)^T$, The weight vector of the output index is $U=(u_1,\ldots,u_s)^T$, and the relative performance of the kth enterprise h can be obtained by solving the following fractional programming problems:

$$max h_k = \frac{\sum_{r=1}^{n} U_r y_{rk}}{\sum_{i-1}^{m} V_i x_{ik}} \tag{1}$$

$$s.t. \frac{\sum_{r=1}^{n} U_r y_{rk}}{\sum_{i-1}^{m} V_i x_{ik}} \leq 1, j = 1,2,\ldots,n \tag{2}$$

$$U_r \geq \varepsilon > 0, r = 1,2,\ldots s$$

$$V_i \geq \varepsilon > 0, i = 1,2,\ldots m$$

(1) Formula is the CCR model in DEA method, where X_{ij} represents the i-th input value of the j-dmu, Y_{rj} represents the r-th output value of the j-dmu, and ε is a non Archimedean number (ε is generally set as 10^{-6}). In order to facilitate the operation and processing, the mathematical dual transformation of formula (1) is carried out so that the pair of even numbers of each restriction is $\theta, \lambda_i, s_r^+, s_r^-$ (s_r^+, s_r^- are relaxation variables), The dual form of the CCR model with non Archimedean infinitesimal to evaluate the overall efficiency of DMU based on input is

$$min[\theta - \varepsilon(\hat{e}^T s^- + e^T s^+)] \tag{3}$$

$$s.t. \sum_{j=1}^{n} \lambda_j x_j + s^- = \theta x_0$$

$$\sum_{j=1}^{n} \lambda_j y_j - s^+ = y_0$$

$$\lambda_j \geq 0, s^- \geq 0, s^+ \geq 0$$

ε is a non Archimedean infinitesimal, $\hat{e}=(1,\ldots,1)^T \in R^m$, $e=(1,\ldots,1)^T \in R^S$, The model can evaluate the comprehensive efficiency of DMU technology and scale. Let the optimal solution of CCR model be $\lambda^*, s^{-*}, s^{+*}, \theta^*$.

The BCC model with non Archimedean infinitesimal to evaluate the pure technical efficiency of urban logistics DMU based on input is:

$$min\, \sigma - \varepsilon(\hat{e}^T s^- + e^T s^+) \tag{4}$$

$$s.t. \sum_{j=1}^{n} \lambda_j x_j + s^- = \sigma x_0$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0, s^- \geq 0, s^+ \geq 0$$

BCC model is used to evaluate the pure technical efficiency of DMU, let the optimal solution of the model be λ^*, s^{+*}, s^{-*}, σ^*.

Scale efficiency reflects the distance between the production frontier with constant returns to scale and the production frontier with variable returns to scale.

Method of judging returns to scale:

If $\theta^* = \sigma^*$, then the return to scale remains unchanged, it reaches the maximum output scale point;

If $\theta^* < \sigma^*$, For CCR λ^*:

If $\sum_{j=1}^{n} \lambda_j^* < 1$, the return to scale is increasing. The smaller the value is, the larger the increasing trend of scale is, which indicates that the output of DMU will be increased by a higher proportion with proper increase of input on the basis of input X_0;

If $\sum_{j=1}^{n} \lambda_j^* < 1$, the returns to scale are decreasing. And the larger the value is, the greater the decreasing trend is, which indicates that on the basis of DMU input x0, increasing input can not bring higher proportion of output, and there is no need to increase the input of DMU.

2.3. Empirical Analysis on the benefit evaluation of joint distribution (taking Xueyuan Road in Haidian District as an example)

- Evaluating indicator.

This study selects three input variables and two expected output variables. The three inputs are as follows: (a) area of sorting area, which refers to the infrastructure investment of enterprises participating in terminal sorting and distribution (b) The number of vehicles refers to the number of main vehicles that enterprises participate in the distribution, which reflects the transportation level of distribution (c) The number of employees refers to the total number of employees in each enterprise. The two ideal outputs are daily income and carbon emissions. Daily revenue refers to the total revenue generated by distribution services after deducting operating costs. Carbon emission is the total amount of carbon dioxide produced by terminal distribution, which mainly comes from the operation of coal-fired vehicles and electric vehicles.

One of the main challenges of enterprise environmental assessment is the collection and standardization of environmental data, especially in the field of freight transportation. According to a review by Murfield [21], there are few comprehensive data sets on transport emissions (e.g., by source, time range, or freight and passenger transport). Using empirical data to establish a baseline of environmental transport performance is essential to understand the impact of freight transport on sustainability. Therefore, according to the vehicle and transportation situation of college road network, the carbon emission calculated is taken as the evaluation criterion of environmental data. See the table 1 for details.

Table 1: Evaluation index

The index type	The index name	variable	unit	Indicators show
Input indicators	Sorting area	X_1	Square meters	Sorting and distribution at the end of the reactions involved in infrastructure spending
	Number of vehicles	X_2	car	Response to participate in the distribution of main traffic tools
	Number of personnel	X_3	a	The reactions involved in logistics at the end of the employer
Output indicators	Daily earnings	Y_1	yuan	Reaction enterprise income levels at the end
	Carbon emissions	Y_2	kg	Reaction from the end of the environmental benefits

Taking Xueyuan Road, Haidian District, Beijing as an example, this paper calculates the input and output indicators according to the actual data of express companies [22].

Suppose that the joint distribution mode of Xueyuan Road is as follows: a joint distribution center is established in a certain area of Xueyuan Road. After each express network transports express mail from its Beijing Distribution Center to the joint distribution center, it will sort together and distribute uniformly to the terminal distribution service station.

It is assumed that after the establishment of the joint distribution center, all express outlets will conduct joint distribution according to the following principles:

(1) It is assumed that the delivery volume of each express outlet remains unchanged before and after joint distribution.

(2) When calculating the site area change of express outlets, only the area of sorting area is considered. After the implementation of joint distribution, the area of the sorting area is estimated according to the daily average total delivery volume and the actual operation mode.

(3) The number of trucks in each express network remains unchanged to maintain the current situation of express transportation from the urban distribution center.

(4) According to the survey, the number of drivers of each express company is basically the same as the number of motor vehicles. Therefore, after the implementation of joint distribution, the number of drivers and the number of vehicles will be maintained the same.

(5) The calculation method of daily profit is daily income minus cost. Logistics cost is divided into fixed investment, transportation cost, labor cost and depreciation cost. Considering the actual situation of express outlets and for simple calculation, the area of sorting area is mainly considered when calculating the rental fee; The transportation cost consists of fuel / maintenance / electricity and parking expenses of the vehicle; Estimate the labor cost per piece of end express according to Literature and actual research; Depreciation cost mainly refers to vehicle depreciation.

According to the above principles, the input and output indicators before and after the implementation of joint distribution are calculated, and the results are shown in Table 2.

Table 2: Data input and output before and after joint distribution

Express outlets	**Sorting area (m^2)**	**Number of vehicles**	**personnel**	**profits**	**Carbon emissions (kg)**
Zhongtong express	440	52	66	3019.21	7.46
Shentong express	240	43	54	1415.76	3.53
Yuantong express	340	33	54	3435.70	5.15
Huitong express	170	21	29	1507.71	4.12
YunDa express	290	24	39	3038.11	4.22
Joint distribution outlets	1080	50	142	15513.76	7.75

Matlab is used to solve the DEA model to evaluate the economic and environmental benefits of joint distribution terminal.

- Economic benefit evaluation.

According to the calculation, before the implementation of joint distribution, the average comprehensive technical efficiency of input and output of express enterprises is 0.806, the average pure technical efficiency is 0.873, and the average scale efficiency is 0.921, which indicates that the resource allocation and management of these express enterprises have reached a more reasonable situation.

It can be seen from the Fig 1. that after the implementation of joint distribution, the comprehensive technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) of the joint distribution outlets all reach DEA efficiency, which indicates that the logistics resource allocation and management are optimal at this time, while the SE of all enterprises' individual distribution is less than 1, and the average TE, PTE and SE are all decreased, which indicates that the joint distribution network can be operated in the future Under the same distribution background, the resource allocation of individual distribution is unreasonable. Among them, the non DEA efficiency of Zhongtong, Shentong and Yuantong is neither pure technical efficiency nor SE, which indicates that there are problems of input redundancy or insufficient output. From the point of view of the increase in the proportion of input and output, it shows that the proportion of increase in the scale of the three enterprises is greater than that of the increase in the scale and output of the three enterprises. As far as Shentong express company is concerned, there is a big redundancy in investment, so we should pay attention to reduce excessive blind investment.

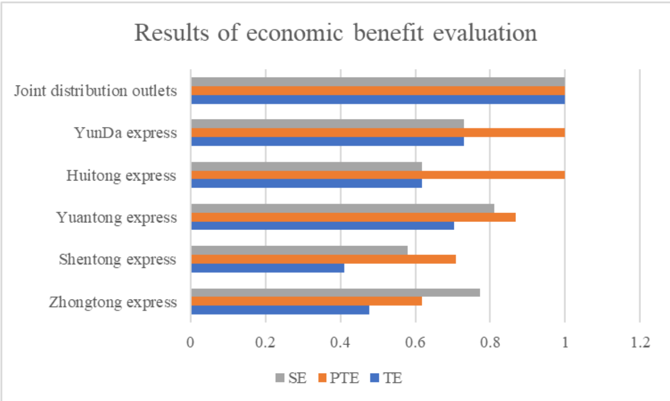

Fig. 1: Economic benefit evaluation results

- Environmental benefit evaluation.

To evaluate the environmental benefits before and after the implementation of joint distribution, the terminal carbon emission is considered as the output evaluation index, so the number of input vehicles is the number of Jinbei, tricycles and new energy vehicles participating in terminal transportation. After adjusting the data, DEA model was used to evaluate the environmental benefits. The results are shown in the table 3 below.

Table 3: End data adjustment results

Express outlets	Area of sorting area (m^2)	Number of vehicles	personnel	profits	Carbon emissions (kg)
Zhongtong express	440	38	66	3019.21	7.46
Shentong express	240	20	54	1415.76	3.53
Yuantong express	340	27	54	3435.70	5.15
Huitong express	170	21	29	1507.71	4.12
YunDa express	290	22	39	3038.11	4.22
Joint distribution outlets	1080	36	142	15513.76	7.75

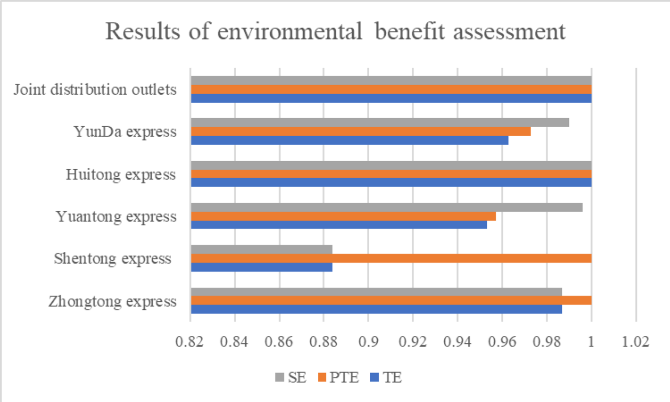

Fig. 2: Environmental benefit evaluation results

For the environmental benefits generated by the end distribution of express enterprises, the comprehensive technical efficiency, pure technical efficiency and scale efficiency of the joint distribution network reach DEA efficiency after the implementation of joint distribution, which indicates that the carbon emission situation at this time is the best and the environmental benefit is the largest. The scale efficiency of single distribution is less than or equal to 1, which indicates that under the background of joint distribution, the environmental benefits of individual distribution are less than or equal to that of joint distribution. Among them, the non DEA efficiency of Yuantong and Yunda enterprises is neither pure technical efficiency nor scale efficiency, and it can be seen from the table that there is obvious investment redundancy. From the perspective of economies of scale, Shentong and Yunda are in the process of increasing returns to scale, which indicates that the increase proportion of unit output will be greater than that of input; on the contrary, Zhongtong and Yuantong are on the decline of scale, indicating that the increase proportion of unit input is greater than that of output. As far as Yunda express company is concerned, it is necessary to pay attention to reduce excessive blind investment.

2.4. Conclusion

Considering the urgent need of logistics cost reduction and energy saving and emission reduction, the main contribution of this study is to use DEA model to calculate and evaluate the economic and environmental benefits of joint distribution. This study takes five express companies in Xueyuan Road of Haidian District of Beijing as the research object, and makes comparative evaluation and Analysis on the survey results. In the main research results, we estimate that through the joint distribution, the economic profit of the university road can be improved, the carbon emission can be reduced, and the economic and environmental benefits can be better than the single distribution. Therefore, the implementation of joint distribution will promote the economic and green development of urban rapid distribution service system, which is of great significance to the sustainable development of urban economy and environment.

The implementation of joint distribution is a complex process, which should be examined from a systematic point of view and comprehensively consider various factors such as manpower, resources and time, so as to ensure that the established system can achieve the expected objectives. First of all, we should understand the actual logistics situation of participating member enterprises and set access conditions. Then, on the basis of multi-party cooperation, build a common distribution system and design the distribution system. Finally, the benefit distribution scheme is designed and the system simulation demonstration is carried out. The specific organization forms of joint distribution are mainly divided into two types: (1) cooperative joint distribution mode. In this mode, the ownership of transportation tools and logistics facilities of all enterprises remains unchanged, and the basic logistics facilities are coordinated and shared. All enterprises establish a coordination mechanism to ensure the normal progress of joint distribution. (2) Rebuild basic logistics facilities such as distribution centers. Under this mode, the re location and route planning of regional distribution center is conducive to give full play to the benefits of economies of scale.

The results of our study will encourage local governments to implement more effective policies and regulations in the future. It is suggested that express enterprises should avoid vicious competition, implement joint distribution, reduce resource waste, and support professional third-party enterprises to provide unified and standardized services for terminal consumers. Standardized unified express, actively promote new energy express, and accelerate the construction of supporting infrastructure such as charging stations and maintenance departments.

This study takes Beijing as an example to evaluate the economic and environmental benefits of joint distribution, but there are still some limitations. First of all, since it is difficult to obtain the distance data for each vehicle, we assume that all express items come from one logistics center. Second, the estimation of carbon emissions comes from the distribution section and average distribution distance, and does not consider the difference of fuel consumption and power consumption of the same vehicle model with different loads and different brands. Thirdly, the DEA model can not be used to evaluate the benefits, and the specific optimization data can not be obtained. Future research may include but not limited to: the actual trajectory data of each vehicle can be obtained through vehicle positioning device, so as to estimate carbon emissions more accurately; combined with other models, specific optimization data can be obtained while the evaluation is realized.

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