Efficiency evaluation of green supply chains based on fuzzy chance constrained three-stage DEA model

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Abstract: Nowadays, environmental pollution and resource waste are in the way of economic development of companies. Hence, it is vital to balance the relationship of economy, society and environment. Based on this, green supply chain management comes into being. Efficiency evaluation, being a main premise of implementing green supply chain management, not only can get knowledge of the overall performance of a company, but also can discover the inefficient parts. In a word, evaluating the performance of green supply chain is a hot topic in recent years. Traditional DEA model treats DMU as a “black box”, which makes the efficiency value higher than that of actual one. Based on it, we study deeper into every subsystems of the overall supply chain, accompanied by multi objective programming model and network DEA model. In the process of coping with the proposed multi objective network DEA, we apply AHP method to determine the weights of each subsystem. In addition, considering the data observed is not always crisp and precise, therefore, we describe them with fuzzy data, and then apply chance constrained possibility programming to cope with it. In the case study, taking 10 enterprises for example, we calculate the overall efficiency and each subsystem’s efficiency value, and propose managerial insights.

1. Introduction
Economically today, issues such as the efficiency of resource use and environmental protection have received extensive attention from entrepreneurs and scholars. The Chinese government is gradually introducing relevant laws and policies in order to attract more and more companies to implement green supply chain management strategies to adjust company operations. Facing the call of the state, it is necessary for enterprises to improve their environmental protection awareness while pursuing economic benefits. Adopting green supply chain management not only satisfies the call of the country, but also assists companies in enhancing their social reputation and economic strength.

Green supply chain management puts more emphasis on green, requiring companies to weigh economic development, social reputation and environmental protection, and protect the relationship among the three. However, in order to speed up the implementation of green supply chain management, it is necessary to have a clear understanding of the actual operation status of the supply chain. Then, it is necessary to evaluate the efficiency of each stage and the whole supply chain through certain models and methods, so as to optimize the operation process of the supply chain from part to the whole.

The concept of the traditional green supply chain originated from green procurement, and has now developed into a complex large-scale system covering multiple stages. Different scholars and experts have their own views on the green supply chain. Srivastava believes that the green supply chain is a
supply chain that has considered its impact on the environment [1]. The green supply chain circulates from product design, material procurement, product production, distribution, and product recycling. Handfield et al. emphasized that green environmental protection elements cannot be ignored in the production process [2]. From the perspective of "sustainability", Jung thinks about and designs the entire process of the supply chain, emphasizing that the cooperation between members will help the green supply chain to achieve the best [3]. Lu added "green" to the supply chain of agricultural product production and sales, and required to ensure that the process is green and environmentally friendly and minimize the damage to the environment [4]. Then, green supply chain management can be defined as the trade-off between economic benefits, environmental protection and resource utilization throughout the product life cycle to ensure that the company enhances its environmental responsibility awareness while improving the level of economic development. Improve its overall image. In short, the evaluation of green supply chain efficiency should include traditional efficiency standards and evaluation of "green" and "environmental" factors.

With the improvement of people's cognition of efficiency, the research on efficiency no longer focuses on economic efficiency, but involves all aspects of social development. Therefore, many research methods related to efficiency have been gradually proposed. Among them, DEA is suitable for multi-input and multi-output activities, and can evaluate the relative effectiveness of various decision-making units. In addition, the weights between various indicators can be calculated by the DEA model, rather than determined by human preference. As a result, the evaluation results are more objective. Therefore, DEA as the main research tool has been applied to the efficiency analysis of all walks of life. In 1986, Charnes came to China and introduced the knowledge about DEA. Since then, Chinese scholars have begun to explore its principles and applications. However, due to the late start, the domestic evaluation of the green supply chain is still relatively small.

The traditional DEA model treats each decision-making unit as a "black box", with only the initial input and final output, ignoring the influence of intermediate variables. However, with the deepening of research, an obvious trend is that the traditional "black box" model is gradually opened to reveal the contribution of various elements in the production process to the total efficiency, and then targeted improvements to enhance the total efficiency. For example, Färe and Grosskopf pointed out that many traditional DEA models are carried out in the "black box" for efficiency research, and then proposed a network DEA model [5]. In addition, scholars have conducted research on online DEA from different perspectives [6-10]. Network DEA is a method to open the "black box" to study the efficiency of decision-making units, that is, to conduct multi-stage analysis of the information radiated from the "black box" from the initial input to the final output, and to restore its internal structure. Therefore, this article intends to establish a three-stage DEA model to evaluate the green supply chain.

With the deepening of research, Hailu and Veeman, Watanabe and Tanaka, and Zhou and Ang all pointed out that economic production will produce some unnecessary additions, that is, undesired output. Therefore, the undesired output is ignored. The efficiency value of is inaccurate [11-13]. Song et al. pointed out when studying the efficiency of industrial systems that only the efficiency of environmental factors and economic factors can fully reflect the real situation of industrial systems [14]. In the green supply chain, the emission of waste gas is regarded as an undesired output. Scholars have proposed different methods to deal with undesired output. Mainly include direct processing methods and indirect processing methods. Direct method: treat undesired output as input, that is, minimize undesired output. Indirect method: use functions to transform undesired output.

Moreover, the previous articles believed that the data can be obtained accurately, and ignored the ambiguity of the data due to measurement errors, data noise, and inconsistent evaluation standards. In actual production and management, various attributes of things can exist in two states, both deterministic and non-deterministic. The non-deterministic state mainly includes random non-determinism and fuzzy non-determinism. Deterministic information is just an ideal value. This article considers the superiority of fuzzy numbers, and feels that the results obtained after introducing fuzzy numbers can truly reflect the information that cannot be accurately quantified. In the past, the treatment of fuzzy numbers often used simplified treatments, such as replacing them with average
values or approximate values, or giving up the in-depth discussion of these uncertainties. This kind of ignores the deep mining of fuzzy numbers, which is easy to cause description bias and seriously distort the authenticity of the evaluation results. Therefore, in the actual calculation process, uncertain indicators and data must be considered. Then, input or output cannot all be represented by accurate numerical values. In this article, the equipment technology level of the supplier, the flexibility of the supplier, the quality of service provided, the ability of the supplier, the reputation of the manufacturer, and the customer satisfaction degree are represented by the LR fuzzy number.

In short, this article will open the "black box" of decision-making units, deal with undesired output and fuzzy numbers, and study the efficiency of the internal subsystems of each decision-making unit and the overall efficiency of the supply chain by constructing a three-stage DEA model.

2. Modelling

2.1 Problem description-green supply chain management
The green supply chain includes four main bodies: suppliers, manufacturers, retailers, and consumers, and involves activities such as green raw material procurement, green production, and green product sales.

The first stage: the procurement of green raw materials, the goal of this stage is to purchase raw materials with high quality, low energy consumption and fast delivery. The input indicators selected at this stage include raw material costs, transportation costs, personnel costs, quality monitoring costs, advertising costs, and reliability costs; output indicators include: number of parts, equipment technology level, supplier flexibility, supplier capabilities and provision service.

The second stage: the green manufacturing stage, the production of low-cost, low-energy, low-polluting products, the selected output indicators are: green product output, manufacturer reputation and carbon dioxide emissions; in addition to the number of intermediate product parts, it also includes Additional investment in green production planning costs and transportation costs.

The third stage: the green product sales stage, the main goal is to achieve the largest green sales volume, while meeting customer needs and improving customer satisfaction. Among them, the environmental impact of packaging and transportation methods must be considered. The number of green products, personnel expenses, and transportation costs are the inputs at this stage; the output is the number of green products sold, customer satisfaction, and on-time delivery.

In this three-stage green supply chain, the raw material procurement stage and the manufacturing stage are mainly connected through raw materials, and the manufacturing and sales stages are mainly connected through green products.

2.2 Three-stage BCC model
In addition to opening the "black box" of the decision-making unit, this model considers the existence of undesired output and fuzzy numbers. In the actual production process, as expected output increases, undesired output (substances that have a negative impact on the environment) will also be produced. Therefore, in order to ensure that the DEA of the decision-making unit is effective, it is necessary to minimize the undesired output and input on the basis of maximizing the expected output. According to the respective goals of each subject, this section establishes a multi-objective network DEA model (1) based on the input and output characteristics of the green supply chain, in which

\[ \sum_{i} v_i d_{iC} + \sum_{j} r_j n_{jG} + \sum_{k} u_{kj} k_{kj} + \sum_{l} w_{lG} + e_{o} \]

represents the weight of each input and output, that is, the decision variable. The first goal is investment-oriented, the goal is to reduce procurement costs, sourcing high-quality raw materials with low production energy consumption and fast distribution; the second goal is investment-oriented, the goal is to produce low cost, low energy consumption, and pollution Few products. The third goal is output-oriented. The goal is to achieve maximum sales while meeting customer needs and increasing satisfaction.
2.3 Solution procedure

The multi-objective model (1) is transformed into a single-objective model (2) through the weighted summation method, and the weights \( \omega_1, \omega_2, \omega_3 \) of each stage is solved by AHP method are used. For fuzzy numbers, this paper uses the fuzzy chance constrained \( P \) programming processing model (2) to obtain the equivalent model (3). In all, we get the efficiency value of the entire supply chain and the efficiency value of each link. Among them, \( \frac{1}{m} \theta_1, \frac{1}{q + c + p} \left( \theta_s + \theta_t + \theta_b \right), \frac{1}{s} \theta_r \) represent the efficiency values of suppliers, manufacturers, and retailers, respectively.

\[
\begin{align*}
1 & \quad \min_{\theta^A} \quad \sum_{t=1}^{n} X_t^A v_t + \mu^A \\
1 & \quad \min_{\theta^B} \quad \sum_{t=1}^{h} Z_{t}^{BC} d_{t}^{BC} + \sum_{t=1}^{h} \bar{Y}_{t}^{B} w_{t} + \mu^B \\
\theta^C & \quad \max_{\theta^C} \quad \frac{\sum_{t=1}^{h} \bar{Y}_{t}^{C} u_{t} - \mu^C}{\sum_{t=1}^{h} Z_{t}^{BC} d_{t}^{BC} + \sum_{t=1}^{h} \bar{Y}_{t}^{B} w_{t}} \\
\text{s.t.} \quad & \sum_{t=1}^{n} Z_{t}^{AB} n_{t}^{AB} + \sum_{t=1}^{h} \bar{Y}_{t}^{A} s_{t} \leq 1, j = 1, 2, \ldots, n \\
& \sum_{t=1}^{n} X_t^A v_t + \mu^A \\
& \sum_{t=1}^{h} Z_{t}^{BC} d_{t}^{BC} + \sum_{t=1}^{h} \bar{Y}_{t}^{B} w_{t} \leq 1, j = 1, \ldots, n \\
& \sum_{t=1}^{h} \bar{Y}_{t}^{C} u_{t} - \mu^C \\
& \sum_{t=1}^{h} Z_{t}^{BC} d_{t}^{BC} + \sum_{t=1}^{h} \bar{Y}_{t}^{B} w_{t} \geq 0
\end{align*}
\]
\[ \begin{align*}
\min \left( \frac{1}{m} \theta_1 + \frac{1}{q + c + p} \left( \theta_2 + \theta_3 + \theta_4 \right) - \frac{1}{s} \theta_r \right) \\
\sum_{i=1}^{n} \lambda_i X^A_i \leq \theta_i X^A_{i_0} \\
\sum_{i=1}^{n} \lambda_i Z^B_{x_0} \geq Z^A_{x_0} \\
\sum_{i=1}^{n} \lambda_i \tilde{Y}^A_{x_0} \geq \tilde{Y}^A_{x_0} \\
\sum_{i=1}^{n} \eta_i Z^A_{x_0} \leq \theta_i Z^A_{x_0} \\
\sum_{i=1}^{n} \eta_i X^B_i \leq \theta_i X^B_{i_0} \\
\sum_{i=1}^{n} \eta_i Y^B_{x_0} \leq \theta_i Y^B_{x_0} \\
\sum_{i=1}^{n} \eta_i Z^C_{x_0} \geq Z^C_{x_0} \\
\sum_{i=1}^{n} \eta_i \tilde{Y}^B_{x_0} \geq \tilde{Y}^B_{x_0} \\
\sum_{i=1}^{n} \tau_i Z^C_{x_0} \leq Z^C_{x_0} \\
\sum_{i=1}^{n} \tau_i X^C_i \leq X^C_{i_0} \\
\sum_{i=1}^{n} \tau_i \tilde{Y}^C_{x_0} \geq \theta_i \tilde{Y}^C_{x_0} \\
\sum_{i=1}^{n} \lambda_i = 1, \lambda_i \geq 0 \\
\sum_{i=1}^{n} \eta_i = 1, \eta_i \geq 0 \\
\sum_{i=1}^{n} \tau_i = 1, \tau_i \geq 0
\end{align*} \]
3. Case study

3.1 Data collection
This paper constructs a fuzzy opportunity constraint three-stage network DEA model, evaluates 10 green supply chain data of beverage production in the same industry, verifies the effectiveness of the model, and gives targeted improvement suggestions based on the analysis of the results. This supply chain consists of four main bodies, suppliers, manufacturers, retailers and consumers. The input variables of suppliers include material costs, transportation costs, personnel costs, quality monitoring costs, advertising costs, and reliability costs; output variables include the number of parts, equipment technology level, supplier flexibility, and quality of services provided. The number of parts is an intermediate variable between the supplier and the manufacturer. For the manufacturer, the input includes the transportation cost of transporting parts from the supplier to the manufacturer, as well as the planning cost incurred for green production; while the expected output is generated, undesired output will also meet unexpectedly, including CO2 Emissions (unexpected output) and the number of green products (inter-products), the reputation of the manufacturer (expected output). For retailers, green products, as an intermediate variable between the manufacturer and the retailer, are both the manufacturer’s output and the retailer’s input variable. In addition, the retailer’s input variables include: personnel costs and green product transportation costs; output includes product sales,

\[
\begin{align*}
\min & \left\{ \frac{\omega_1}{m} \theta + \frac{\omega_2}{q + c + p} \left( \theta_1 + \theta_2 + \theta_3 \right) - \omega_3 \frac{1}{\delta} \right\} \\
\sum_{j=1}^{a} & \lambda_j x^s_j \leq \theta x^s_0 \\
\sum_{j=1}^{a} & \lambda_j z^{AB}_j \geq z^{AB}_0 \\
\sum_{j=1}^{a} & \eta_i y^a_i \leq \theta_i y^a_0 \\
\sum_{j=1}^{a} & \eta_i y^b_i \leq \theta_i y^b_0 \\
\sum_{j=1}^{a} & \eta_i y^c_i \leq \theta_i y^c_0 \\
\sum_{j=1}^{a} & \eta_i z^{BC}_j \geq z^{BC}_0 \\
\sum_{j=1}^{a} & \eta_i y^a_i \geq (1-\gamma) \sum_{j=1}^{a} \lambda_j \left( y^a_i \right) \geq (1-\gamma) y^a_0 \\
\sum_{j=1}^{a} & \eta_i z^{AB}_j \leq \theta_i z^{AB}_0 \\
\sum_{j=1}^{a} & \eta_i y^b_i \leq \theta_i y^b_0 \\
\sum_{j=1}^{a} & \eta_i y^a_i \leq \theta_i y^a_0 \\
\sum_{j=1}^{a} & \eta_i \leq 1, \lambda_i \geq 0 \\
\sum_{i=1}^{a} & \lambda_i \geq 0 \\
\sum_{i=1}^{a} & \eta_i \geq 0 \\
\sum_{i=1}^{a} & \eta_i \geq 0 \\
\end{align*}
\]
customer satisfaction, quality of services provided, and on-time delivery rate. It is worth emphasizing that the supplier's equipment technology level, the supplier's flexibility, the quality of service provided, the supplier's capabilities, the reputation of the manufacturer, and the customer satisfaction degree are represented by fuzzy numbers.

3.2 Weight decision
Using the analytic hierarchy process to determine the degree of influence of the three sub-links of suppliers, manufacturers, and retailers on the overall efficiency, the actual operation of AHP is as follows:

Step 1: Build an evaluation structure.
- The first level (target level) \( U = \{ \text{overall efficiency of green supply chain} \} \)
- The second level (evaluation level) \( U = \{ \mu_1, \mu_2, \mu_3 \} = \{ \text{supplier, manufacturer, retailer} \} \)
- The third level (indicator level) involves financial, customer, process, development, environmental protection, and social aspects. The details are as follows:
  - Financial aspect: energy consumption, carbon dioxide emissions, green planning cost, number of green products
  - Customer aspect: punctual arrival rate, percentage of green products sold, customer satisfaction, green product sales growth rate, green product market growth rate

Step 2: Construct a judgment matrix. The implicit condition is to pass the consistency test.
Step 3: Calculate the importance and output the result.
Therefore, the values of \( \omega_1, \omega_2, \omega_3 \) obtained respectively are: (0.25, 0.65, 0.1).

3.3 Efficiency analysis
As shown in Table 1 and Figure 1, four of the Behnoush, Kafir, Dandaran, and Pegah companies are DEA valid, and the remaining 6 companies are non-DEA valid, which shows that these 6 companies still have redundant resources or insufficient output problem. On the contrary, the four effective DMU companies have the best ratio of input and output, which is an ideal green supply chain structure. Then, for companies that are not DEA effective, they can be encouraged to achieve DEA effectiveness by strengthening internal link management. Table 1 and Figure 1 not only show the overall efficiency of the green supply chain, but also detail the efficiency values of suppliers, manufacturers, and retailers. Based on this, this article will take Khazar as an example in the next section to analyze its efficiency improvement direction and improvement approach.
Figure 1 overall efficiency values in terms of different stages

For companies that are not DEA effective, they can achieve DEA effectiveness through different adjustment methods, such as reducing input or increasing output. Take DMU5 (Khazar) as an example. Its suppliers and retailers are DEA valid, but the manufacturer is not DEA valid. Khazar needs to adjust the undesired output, the three inputs and the expected output, that is, green planning costs are reduced by 6.7%, transportation costs are reduced by 25.1%, CO2 emissions are reduced by 7.2%, and the production of green products is increased by 11 units; After the adjustment, the company will be on the frontier of being able to be effective, that is, DEA is effective. The adjustment process is shown in Table 2.

Table 1 Evaluation of stages’ efficiencies and overall efficiencies

| Green supply chain | Behnoush | Abali | Kafir | Zam | Zam | Khazar | Dandaran | Sara | Remark | Pegah | Varna |
|--------------------|----------|-------|-------|-----|-----|--------|----------|------|--------|-------|-------|
| Supplies           | 1.000    | 1.000 | 1.000 | 1.000 | 1.000 | 0.954 | 1.000    | 1.000 | 1.000  | 1.000 | 1.000 |
| Manufactures       | 1.000    | 0.962 | 1.000 | 1.000 | 0.867 | 1.000 | 1.000 | 1.000 | 0.808 | 1.000 | 1.000 |
| Retailers          | 1.000    | 1.000 | 1.000 | 1.000 | 1.000 | 0.944 | 0.984    | 0.983 | 1.000  | 1.000 | 0.954 |
| Overall efficiencies| 1.000    | 0.975 | 1.000 | 1.000 | 0.914 | 0.983 | 0.998    | 0.874 | 1.000  | 1.000 | 0.995 |
| Efficient?         | Yes      | No    | Yes   | Yes  | No   | No     | No       | No   | Yes    | No    |       |
| Rank               | 1        | 8     | 1     | 1    | 9    | 7      | 5        | 10   | 1      | 6     |       |
Table 2 Improvement pathway of film Khazar

| Supplier | Inputs                      | Outputs                  |
|----------|-----------------------------|--------------------------|
|          | Green Planning Costs        | CO2 emissions            |
|          | 0.933*149                   | 0.928*167                |
|          | Transportation cost         | Green product production |
|          | 0.749*526                   | 479+11                   |
|          | Quantity of parts purchased | Manufacturer's reputation |
|          | 0.858*275                   | -                        |

3.4 Comparative analysis
In order to further illustrate the advantages of the network DEA model, this section treats the green supply chain as a "black box", calculates the overall efficiency, and compares it with the efficiency value obtained by the model built in this article. As shown in Figure 2, using the "black box" DEA model, that is, only considering the initial input and final output, ignoring intermediate links and intermediate variables, the solution obtained is larger than that obtained by the three-stage DEA model, and there are many companies at the same time on the effective frontier. Therefore, in contrast, the model proposed in this paper has better discrimination and can better evaluate multiple decision-making units.

Moreover, in real life, the intermediate links of the green supply chain cannot be ignored, because more than one link is involved, including green product design, raw material procurement, production, sales and distribution, etc., so the three-stage network DEA model is more suitable for evaluation of green supply chain.

4. Conclusion
This paper considers "fuzzy number", "green", and "unexpected output", opens up the internal structure of the supply chain, and establishes a three-stage network DEA model of fuzzy opportunity constraints. And we used this model to evaluate the efficiency of the green supply chain in 10 companies. It turns out that most companies are not all DEA effective, that is, there are still too many intermediate links and the expected output fails to reach the target. Therefore, this article takes a
decision-making unit as an example, analyzes its improvement direction and improvement steps, and hopes that this example can give enterprises some enlightenment to improve operations.

Based on the above research and analysis results, this article believes that we can start from the following aspects to improve the economic strength and social recognition of enterprises. For suppliers, its goal is to purchase high-quality, low-energy, low-pollution raw materials, and quickly provide them to manufacturers. Therefore, improving the quality of the supplier's raw materials and the level of distribution can improve the supplier's efficiency. Specifically, it can strengthen its own capacity building by improving the technical level of equipment, controlling the quality of raw materials, and improving flexibility.

For manufacturers, its goal is to produce products at the lowest cost and lowest damage rate, and to select raw materials and production methods with low energy consumption, low waste emissions, and low environmental pollution. Specific measures include: First, learn foreign innovative green production tools and technologies, and make them suitable for the company's products through the process of "absorption-improvement-utilization". Secondly, recruit high-level management personnel, control costs, and minimize planning costs due to green production. Finally, reduce waste discharge and improve self-reputation.

For retailers, its main goal is to achieve maximum sales while guiding customers' demand for green products. The proportion of the sales of green products in the overall sales reflects the market share of green products to a certain extent, and the magnitude of this value indicates the degree of promotion of "green" products. Therefore, for retailers, first of all, attracting more and more consumers to buy "green" products can better achieve green sales. Secondly, improve its own service level, provide low-cost and high-quality and meet consumers' requirements for services and products.

Finally, as far as the government is concerned, companies are required to establish a "green and sustainable development" concept, which can specifically guide companies to implement green supply chain management measures through certain material incentives. In addition, it is recommended that the government can provide enterprises with a fair competition environment of "purchasing low-cost and high-quality materials, producing green products with high resource utilization and low environmental impact, selling green products, and repurchasing products". Many companies adopt green supply chain management measures.

This article uses a weighted sum method to transform the multi-objective problem into a single-objective problem. However, as scholars deepen their research on multi-objective programming problems, solving multi-objective problems has been extended to interactive solving methods, including STEM, trade-off ratio substitution method. These methods enable decision makers to obtain a more satisfactory Pareto solution. Therefore, in future research, we can try to use different solutions to explore the most satisfactory solution.

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