# Selection of Optimal Third-party Logistics Recycler Based on Fuzzy DEA

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**Abstract.** Selection of appropriate third-party logistics recycler in closed loop supply chain management strategy (CLSCMS) is a challenging issue because it requires a lot of evaluation criteria/attributes, which are characterized with complexity, elusiveness, and uncertainty in nature. This paper proposes a fuzzy confidence DEA evaluation model to assist the expert group to select the optimal third-party logistics recycler in CLSCMS. A case manufacturing firm is studied and the results indicated that the proposed evaluation model is simple, reasonable and effective to determine the optimal third-party logistics recycler. This fuzzy confidence DEA evaluation model provides a complete picture in CLSCMS contexts to both researchers and practitioners.

## 1. Introduction

As the environment is deteriorating, mandatory laws were enforced by the government, the core enterprises in traditional supply chain concern about the recycling and reuse of products more and more. The so-called reverse supply chain has emerged. In order to improve core competitiveness, the manufacturer usually outsources reverse logistics to a third-party logistics recycler, so that it can focus more on its core areas. Therefore, the success of a reverse supply chain is highly dependent on selection of good recyclers. Recycler selection involves the need to trade-off multiple criteria, as well as the presence of both quantitative and qualitative data. To manage this strategically important purchasing function effectively, appropriate method and criteria have to be chosen for the problem. Over the years, several techniques have been developed to solve supplier selection efficiently. Analytic hierarchy process (AHP), analytic network process (ANP), linear programming (LP), mathematical programming, multi-objective programming, data envelopment analysis (DEA), neural networks (NN) and case-based reasoning (CBR) methods have been applied in literature. Wu and Barnes [1] drew on Dempster-Shafer theories and optimization in developing a method for formulating criteria to use in partner selection decision-making in ASCs. Their model offers a way of solving this problem under conditions of resource constraints. Saen [2] also proposed a DEA-based methodology for supplier selection. The strong point of her/his model is that it considers both undesirable outputs and imprecise data simultaneously. To increase the supplier selection and evaluation quality, Zeydan et al. [3] considered both qualitative and quantitative variables in evaluating performance for selection of suppliers based on efficiency and effectiveness. In their model, qualitative variables are transformed into a quantitative variable for using in DEA.

But there are few researches on recycler selection and previous recycler selection models are mainly based on certain or stochastic environment with less emphasis on fuzzy environment. The main contribution of this paper is to propose a fuzzy confidence DEA model for finding most efficient recycler in closed loop supply chain. By considering the characteristics of cooperative relations between the core enterprise and the third-party logistics recycler in closed loop supply chain, linguistic variables are used to assess the weights of all criteria and the rating of each alternative with respect to each criterion.

## 2. Criteria system about third-party logistics recyclers

The third-party logistics recycler is one of the generalized management bodies in supply chain, so the criteria feature set of third-party logistics recyclers should not only reflect service criteria, such as, quality, delivery, price, but also include development and coordination criteria of supplier, such as collaborative capacity, technology and development capabilities, development capacity.

The principles of criteria system establishment.

(1) Comprehensive principle: the criteria system can not only reflect the supplier's current conditions fully, but also reflect the future development trends of the supplier.

(2) Flexible operational principle: the criteria system should be established flexibly, which can be used by enterprises according to their own characteristics and actual situation.

(3) Scientific and practical principle: the criteria system should be moderate, practical and can reflect the actual situation of the supplier scientifically. If the criteria system is too large, it will not reflect the overall; if the criteria system is too small, it will not reflect the actual situation of the supplier.

(4) Expanding principle: Since each enterprise in industry has its own special requirements, some special criteria should be added to the criteria system, which requires criteria system and evaluation model should be expanded.

When the manufacturer selects a third-party logistics recycler as cooperation partner from many alternative recyclers, there are five main criteria in fuzzy evaluation criteria system, including cooperation credibility, technical capability, service capability, quality and business performance. According to China's manufacturing industry development situation, this paper adopts the criteria system in the literature [4]. The price is a weighted average price in which weights are calculated by the batch shipments; Price multiplied by delivery history is the total purchasing quantity($X_1$); Late delivery quantity($X_2$), the amount of products which are not delivered on time, is criteria of punctual delivery; Delivery response time($X_3$) from the recycler receiving the delivery notice to large delivery is criteria of agile delivery, calculated by the number of days; Availability of recycled goods is criteria of quality, since DEA model is not affected by dimensions, availability×100($Y_1$) is used instead of availability in calculation; Delivery history($Y_2$) is the amount of past total ordering. In the above criteria, purchase amount, punctuality and agility of delivery are input criteria of the evaluation model, the smaller the better; Quality and delivery history are output criteria, the bigger the better; Result of evaluation is criteria of relative effectiveness for the recyclers.

## 3. Fuzzy confidence DEA model of third-party logistics recyclers

Fuzzy DEA method is a non-parametric method, which can be used to determine production frontier and relative effectiveness of the Evaluation and Decision Making Unit (DMU). It is developed on the basis of the classic data envelopment analysis and inherits all the advantages of the classical DEA method. It requires fewer criteria, but has higher sensitivity and reliability, and can analyze criteria which are not transformed to price or even difficult to determine the weights. Each measure can appear in its original face, their units do not need to be unified. This greatly simplifies the measurement process, guarantees the integrity of the original information, and avoids subjective impact of weights determination.

**Definition 1:** A fuzzy number $\tilde{A}$ is called L-R, if its membership function has the following form:

$$m_{\tilde{A}}(x)=\begin{cases}0 & x<\underline{a}\\ L\left(\dfrac{a-x}{c}\right) & \underline{a}\le x\le a\\ 1 & x=a\\ R\left(\dfrac{x-a}{d}\right) & a<x\le\overline{a}\\ 0 & x>\overline{a}\end{cases}\qquad(1)$$

Where $L$:[0,+ ∞]→[0,1],$R$:[0,+ ∞]→[0,1],$L$(0)=$R$(0)=1, $L\left(\frac{a-\underline{a}}{c}\right)=R\left(\frac{\overline{a}-a}{d}\right)=0$,$L$ and $R$ are the increasing and decreasing continuous functions respectively. The pictorial representation of the above membership function is Fig. 1. We will use the notation $\tilde{A}=\left[\underline{a},\overline{a}\right]$ for LR-type fuzzy number in our discussions.

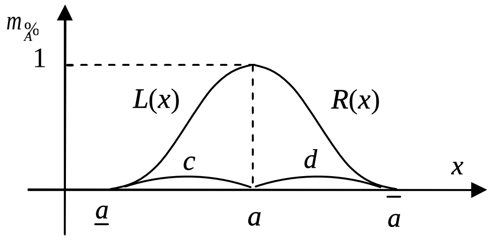


Fig. 1 LR-type fuzzy number

**Definition 2:** If possibility of $\tilde{A}\geq\tilde{B}$ is $a$,then the confidence level of $\tilde{A}\geq\tilde{B}$ is $a$, denoted by $\Gamma\left(\tilde{A}\geq\tilde{B}\right)=a$ .

**Definition 3:** Suppose $\tilde{A}=\left[\underline{a},\overline{a}\right]$ and $\tilde{B}=\left[\underline{b},\overline{b}\right]$ are both LR-type fuzzy numbers, $\Gamma\left(\tilde{A}\geq\tilde{B}\right)$ is confidence of $\tilde{A}\geq\tilde{B}$, then

$$\Gamma\left(\tilde{A}\geq\tilde{B}\right)=\min\left(\frac{\max\left(\overline{a}-\underline{b},0\right)}{\overline{a}-\underline{a}+\overline{b}-\underline{b}},1\right)=\begin{cases}1 & \underline{a}>\overline{b}\\ \frac{\overline{a}-\underline{b}}{\overline{a}-\underline{a}+\overline{b}-\underline{b}} & \underline{b}\leq\overline{a}\ \text{and}\ \underline{a}\leq\overline{b}\\ 0 & \overline{a}<\underline{b}\end{cases} \quad (2)$$

Suppose there are $n$ units which need to be evaluated. Each object is denoted by a DMU, and each DMU has $m$ inputs and $s$ outputs，then the fuzzy confidence DEA model with environment variable fuzzy numbers is as follow.

$$\begin{aligned}&\min q_a\\ &s.t.\ \Gamma\left(\sum_{j=1}^{n} l_j\tilde{X}_j\leq q_a\tilde{X}_0\right)\geq 1-a\\ &\Gamma\left(\sum_{j=1}^{n} l_j\tilde{Y}_j\geq\tilde{Y}_0\right)\geq 1-a\\ &l\geq 0,\ j=1,2,\ldots n\end{aligned} \quad (3)$$

After expansion, a deterministic DEA model can be obtained under the condition of confidence

$$\begin{aligned}&\min q_a\\ &s.t.\ \left(\sum_{j=1}^{n} l_j\left(a\underline{X_j}+(1-a)\overline{X_j}\right)\right)\leq q_a\left((1-a)\underline{X_0}+a\overline{X_0}\right)\\ &\left(\sum_{j=1}^{n} l_j(1-a)\underline{Y_j}+a\overline{Y_j}\right)\geq a\underline{Y_0}+(1-a)\overline{Y_0}\\ &l\geq 0,\ j=1,2,\ldots n\end{aligned} \quad (4)$$

This is a $C^2R$ model with confidence level $a$. Confidence level of fuzzy numbers constraints are not less than 1-$a$. Confidence level of obtained effective value is $a$, denoted by $q_a$.

Similar to traditional DEA model, the effectiveness of above model is defined as follows:

(1) If $q_a$=1,then the decision-making unit $j_0$ is known as weak fuzzy DEA effective;

(2) If $q_a$=1 and slack variable equals 0,then the decision-making unit $j_0$ is known as fuzzy DEA effective;

(3) If $q_a$<1, then the decision-making unit $j_0$ is known as non-fuzzy DEA effective;

With the above model, the decision-making units can be comprehensively evaluated with precision number and fuzzy inputs. Solving method is as follows.

(1) First, quantify fuzzy variable criteria of expert evaluation by a certain method, i.e., fuzz them to LR-type fuzzy numbers, such as $\tilde{A}=\left[\underline{a},\bar{a}\right]$.

(2) Select the appropriate input and output criteria.

(3) Evaluate all the alternative third-party logistics recyclers with above fuzzy DEA model. According to practical requirements, select specific values and calculate their efficiency scores.

(4) Compare, analyze and sort all the decision-making units according to the scores of efficiency evaluation.

## 4. Empirical analysis

A manufacturer will select one from many alternate third-party logistics recyclers to cooperate. Information about candidate recyclers is shown in Table 1.

Table 1 Data of the recyclers' criteria

| Recyclers DMU | Total delivery | Late delivery | Response time | Availability | Delivery history |
|---|---|---|---|---|---|
| 1 | [48,50] | [4,6] | [6,8] | [78,80] | [180,185] |
| 2 | [43,45] | [6,8] | [4,6] | [50,52] | [150,155] |
| 3 | [46,48] | [3,5] | [8,10] | [60,64] | [165,170] |
| 4 | [48,51] | [12,14] | [7,9] | [76,78] | [175,180] |
| 5 | [5, 8] | [0 ,2] | [3,5] | [20,24] | [20 , 25] |
| 6 | [12,16] | [1,3] | [0,2] | [48,52] | [50 , 55] |
| 7 | [32,36] | [2,4] | [2,4] | [28,30] | [130,135] |
| 8 | [15,18] | [2,4] | [5,8] | [56,60] | [55 , 60] |
| 9 | [44,48] | [14,18] | [2,5] | [65,70] | [165,170] |
| 10 | [64,66] | [16,18] | [2,4] | [84,86] | [240,245] |

Analyze the decision-making units with the above method. The confidence values are taken as $a$=0.5, 0.6, … ,1 respectively. Let average confidence efficiency be $\bar{q}_a=\frac{1}{k}\sum_{i=1}^{k} q_{a_i}$ . Then the calculated results are shown in Table 2 and Fig.2.

Table 2 DEA evaluation results of recyclers

| | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1.0 | Average | Sequence |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.9797 | 0.9388 | 0.9085 | 0.8621 | 0.8146 | 0.7669 | 0.878433 | 3 |
| 2 | 0.8949 | 0.8709 | 0.8419 | 0.8004 | 0.7568 | 0.7129 | 0.812967 | 9 |
| 3 | 1.0000 | 0.9269 | 0.8712 | 0.8240 | 0.7749 | 0.7271 | 0.854017 | 4 |
| 4 | 0.9307 | 0.9020 | 0.8692 | 0.8246 | 0.7768 | 0.7292 | 0.83875 | 6 |
| 5 | 0.9477 | 0.8571 | 0.7727 | 0.6785 | 0.5950 | 0.5208 | 0.728633 | 10 |
| 6 | 1.0000 | 0.9295 | 0.8635 | 0.7990 | 0.7369 | 0.6771 | 0.834333 | 7 |
| 7 | 1.0000 | 0.9694 | 0.9364 | 0.8825 | 0.8274 | 0.7748 | 0.898417 | 1 |
| 8 | 0.9842 | 0.9252 | 0.8668 | 0.7966 | 0.7293 | 0.6649 | 0.827833 | 8 |
| 9 | 0.9504 | 0.9128 | 0.8778 | 0.8322 | 0.7854 | 0.7383 | 0.849483 | 5 |
| 10 | 1.0000 | 0.9754 | 0.9111 | 0.8703 | 0.8286 | 0.7862 | 0.895267 | 2 |

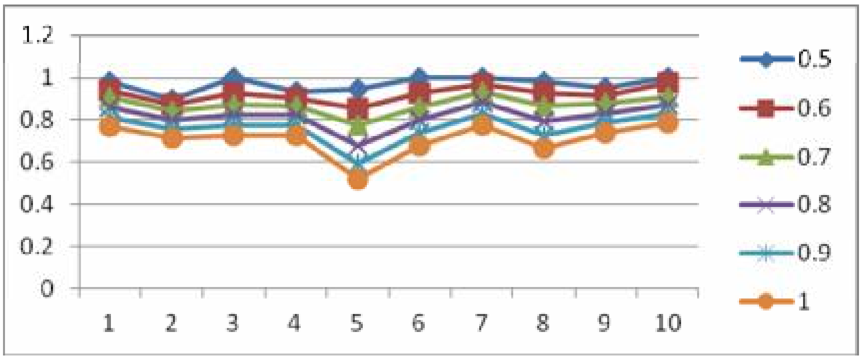


Fig. 2 DEA evaluation results of recyclers

The results show that:

(1) Average confidence efficiency of decision-making unit 7 is highest, followed by which is the decision-making unit 10, average confidence efficiency of decision-making unit 5 is lowest. For the manufacturer, preferred third-party recycler is No. 7 or 10. Average confidence efficiency of decision-making unit 7 is relatively higher, because its punctual delivery time and agile delivery time is shorter, delivery history is bigger. But confidence efficiency of the decision-making unit 5 is less because of longer agile delivery time and less delivery history.

(2) With the increase of the confidence level, confidence efficiency of each DMU is decreasing. Because $q_a$ is a decreasing function of $a$, i.e., the higher confidence level is, the lower the effective value is. This is consistent with practical experience.

(3) Efficiency rating of the decision-making unit in different confidence level is roughly the same, as shown in Figure 1. But ratings among some specific decision-making units change. For example, when confidence level of decision-making unit 1 is 0.5, its efficiency rating is lower than that of decision-making unit 3. However, effective values of whole confidence interval show that effective value of decision-making unit 1 is bigger than that of decision-making unit 3. For decision-making unit 3, a possible reason is that its quality is fuzzier than that of the decision-making unit 1, its interval is wider, so it is less effective than the formers in most of confidence intervals.

## 5. Conclusions

In this study, recycler selection problem which is an important issue in closed loop supply chain strategic design is investigated. In practical CLSCMS problems, there are vast amounts of criteria and attributes with elusive qualitative information. Also considering the difficulties obtaining criteria evaluations in a numerical way, decision makers are asked to evaluate them linguistically. This study developed an effective fuzzy confidence DEA model to select the most appropriate third-party logistics recycler from a finite set of alternatives with reference to multiple criteria in CLSCMS. The proposed evaluation model has been validated with its effectiveness and simplicity in selecting the optimal recycler in CLSCMS for the case firm. The whole supply chain members can apply the proposed model to evaluate and determine firms' optimal recycler in uncertainty.

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