Improved Fuzzy Grey Relational-TOPSIS model for hazardous waste transporter selection

Xuedong Liang\textsuperscript{1,2,3}, Jinrui Miao\textsuperscript{2} and Qian Lu\textsuperscript{2}

\textsuperscript{1} The Economy and Enterprise Development Institute, Sichuan University, Chengdu 610065, China; \hspace{1cm} \textsuperscript{2} Business School, Sichuan University, Chengdu 610065, China
\textsuperscript{3} Email: liangxuedong@scu.edu.cn

Abstract. With the continuous increase of hazardous waste production, environmental protection organizations all over the world pay more attention to it, and each link of the whole life cycle of hazardous waste becomes more and more standardized. Because waste production units (WPU) must strictly abide by the law to transport hazardous waste, and most WPU do not have the relevant qualifications, plus the particularity of hazardous waste, usually choose to outsource this business, so how to choose WPU becomes more important. This paper studies the selection of hazardous waste reverse logistics suppliers. Firstly, based on the characteristics of hazardous waste industry itself, this paper innovatively establishes the evaluation and selection index system of hazardous waste transporter (HWT) from five dimensions including technical capability, service level, economic level, environment and safety and additional services. Then the fuzzy grey relational-TOPSIS (F-GR-TOPSIS) model is established by improving the grey relational-topsis model. Through the fuzzy theory, the qualitative index is quantified, and the grey relational analysis method is used to give the objective weight to the index. Finally, an example is given to verify the effectiveness of the method, which provides a certain reference for WPU to select hazardous waste transporter.

1. Introduction

With the rapid development of the world economy, hazardous wastes from industrial production are increasing day by day. Hazardous waste is more hazardous than general solid waste, and it is difficult to predict the pollution consequences and difficult to safely dispose of it. If not properly handled, it will bring serious secondary pollution to the atmosphere, water and soil, affecting the ecological environment and human health [1]. Due to the corrosive, toxic, inflammable, reactive and infectious characteristics of hazardous waste (including medical waste), compared with the storage and transportation of general goods, more attention should be paid to safety factors. Waste production units usually do not have the national hazardous waste transshipment qualification. Considering the cost and production efficiency, enterprises usually choose to outsource this part of work to qualified HWT [2]. The transportation company selected by the enterprise must first have the certificate issued by the state [3]. Second, the enterprise must be able to carry out legal procedures and correct waste transport and pretreatment. Finally, it is also important for waste production enterprises to have awareness of quality, service and safety [4].

Transportation enterprise selection is a multi-standard decision-making (MCDM) problem. Gumus proposed a two-step method to evaluate hazardous waste transportation companies, ranked HWT using TOPSIS and fuzzy analytic hierarchy process (FAHP) result weights [4]. Kabir believed...
that the uncertainty and imprecise data of factors involved in HWT selection would affect the selection result, so Delphi method, VIKOR method and fuzzy set theory were combined to study a more effective selection model [2]. Buyukozkan believed that the selection problem of HWT first introduced intuitionistic ambiguity in the context of uncertainty and ambiguity [5]. In this paper, considering the status quo and characteristics of the waste industry in China, combined with the actual innovation, a critical waste transport enterprise evaluation index system was proposed. Baranitharan.P on the basis of the grey relational-topsis model adopted in selecting the best pyrolysis process parameters [6], fuzzy theory was introduced to quantify the data and evaluate and select the transportation enterprises, which provided important reference value for the selection of transportation enterprises in hazardous waste industry.

2. Evaluation index system of hazardous waste transportation system

Based on the particularity of the hazardous waste industry, this paper establishes the HWT evaluation and selection index system from five dimensions: technical capability, service capability, economic capability, environment and safety, and additional services. As shown in Table 1.

| Evaluation index of hazardous waste transporter | The Main criteria | Sub - criteria | The Reference |
|-----------------------------------------------|------------------|---------------|---------------|
| 1. Technical capability (TC)                  | Program compliance (PC) | [5]          |
|                                               | Problem solving ability (PSA) | [5]        |
|                                               | Working experience (WE) | [2]          |
| 2. Service capability (SC)                    | Service hours (ST) | [4]          |
|                                               | Quality of service (QS) | [5]          |
|                                               | Flexible (F) | [7]          |
| 3. Economic capability (EC)                   | Cost of service (COS) | [2]          |
|                                               | Financial stability (FS) | [8]        |
| 4. Environment and safety (ES)                | Health and safety (HS) | [5]          |
|                                               | Taking care of human health (TCH) | [5]        |
|                                               | Comply with environmental protection standards (EPS) | [5]       |
| 5. Additional services (CS)                   | Reputation and position (RP) | [9]        |
|                                               | The owned vehicle fleet (OVF) | [4]        |

3. F-GR-TOPSIS model

Although grey relational analysis and TOPSIS model have been popular tools to solve MCDM problems, there are few researches on hazardous waste industry by combining them. Due to the particularity of hazardous waste industry, based on the GR-TOPSIS model adopted by Baranitharan.P to select the optimal pyrolysis process parameters, this paper introduced fuzzy theory and established the F-GR-TOPSIS model to evaluate and select third-party suppliers in hazardous waste reverse logistics. Specific evaluation selection model is shown in Figure 1.
3.1. Establish fuzzy evaluation matrix

For the qualitative index of this paper, the clear data matrix is calculated by fuzzy mathematics theory. The evaluation matrix obtained by each expert can be expressed as

$$X^{(i)} = [X^{(i)}_{jk}]_{n 	imes (k=1,2,...,s)}.$$ Among them, $X^{(i)}_{jk}$ is the k-th expert's fuzzy evaluation value of target i under index j. Using the triangular fuzzy number

$$X^{(i)}_j = (a^{(i)}_j, b^{(i)}_j, c^{(i)}_j),$$

where $a^{(i)}_j$ represents the most conservative estimate, $b^{(i)}_j$ represents the most likely estimate, and $c^{(i)}_j$ represents the most optimistic estimate.

Without loss of generality, this paper assumes that the importance of each expert evaluation is the same, then the evaluation matrix can be calculated as follows.

$$X^{(i)} = \frac{1}{s} \otimes (X^{(i)}_1 \oplus X^{(i)}_2 \oplus ... \oplus X^{(i)}_s) = a^{(i)}_j, b^{(i)}_j, c^{(i)}_j$$

(1)

In the formula, "\( \oplus \)" and "\( \otimes \)" respectively represent the addition and multiplication operations of fuzzy numbers. Then the parameters of each triangular fuzzy number can be obtained by the following formula:

$$a^{(i)}_j = \frac{1}{s} \sum_{k=1}^{s} a^{(i)}_j, \quad b^{(i)}_j = \frac{1}{s} \sum_{k=1}^{s} b^{(i)}_j, \quad c^{(i)}_j = \frac{1}{s} \sum_{k=1}^{s} c^{(i)}_j$$

(2)

3.2. Convert to a clear evaluation matrix

This paper uses commonly used triangular fuzzy numbers. The fuzzy evaluation matrix can be transformed into a clear data matrix. The calculation method is as follows:

$$X^{(i)} = D(X^{(i)}) = \frac{(a^{(i)}_j + 2b^{(i)}_j + c^{(i)}_j)}{4}$$

(3)

Merge the obtained clear data matrix with the quantitative indicator matrix to obtain the evaluation decision matrix $X^{(i)}$ of the acquisition target.

3.3. Weighting of evaluation indicators

HWT selection system is a gray system. In this paper, the fuzzy TOPSIS model is improved and the grey relational analysis method is adopted to give weight to the index factors. The specific steps are as follows:

(1) Data standardization processing:
For the efficiency indicator $y_{ij}$, the greater the better, take
\[
y'_{ij} = \frac{y_{ij}}{\max\{y_{ij}, y_{i2}, ..., y_{ij}\}}
\] (4)
For cost-type indicator $y_{ij}$, the smaller the value, the better, take
\[
y'_{ij} = \frac{\min\{y_{i1}, y_{i2}, ..., y_{ij}\}}{y_{ij}}
\] (5)
Then the standardized value is:
\[
z_{ij} = y'_{ij}
\]
(3) Calculate the correlation degree of indicator factors:
Calculate the correlation coefficient of indicator factors between comparison sequence and reference sequence:
\[
\rho^{\ast}_j = \frac{\min \{Z_{ij}(j) - Z_{ij}(\ast)\} + \rho \max \{Z_{ij}(j) - Z_{ij}(\ast)\}}{\max \{Z_{ij}(j) - Z_{ij}(\ast)\} + \rho \max \{Z_{ij}(j) - Z_{ij}(\ast)\}} - \frac{\max \{Z_{ij}(j) - Z_{ij}(\ast)\} + \rho \max \{Z_{ij}(j) - Z_{ij}(\ast)\}}{\max \{Z_{ij}(j) - Z_{ij}(\ast)\} + \rho \max \{Z_{ij}(j) - Z_{ij}(\ast)\}}
\] (6)
Among them, the $\rho$ to distinguish coefficient, can reduce the influence of extreme value for calculation, and $\rho \in [0,1]$. Generally take $\rho \leq 0.5$, and in this method take $\rho = 0.4$. Correlation degree is the embodiment of the relation between reference sequence and comparison sequence. The calculation formula is as follows:
\[
m_j = \frac{1}{m} \sum_{j=1}^{m} \theta(j)
\] (7)
(4) Calculate the weight of indicator factors:
Here, the following formula is used to calculate the weight of each index:
\[
W_i = \frac{m_j}{\sum m_j}
\] (8)
3.4. TOPSIS analysis
After the weight of indicator factors is obtained, the weighted evaluation matrix is calculated:
\[
V = (V_{ij})_{num} = (W_jZ_{ij})_{num}
\] (9)
(1) Determine the fuzzy positive ideal solution and negative ideal solution as follows:
\[
V^* = \{V^*_{i1}, V^*_{i2}, ..., V^*_{jm}\} \quad \quad V = \{V_{i1}, V_{i2}, ..., V_{jm}\}
\]
Among them, $V^*_{ij} = \max\{V_{ij}, V_{i1}, ..., V_{ij}\}$, $V_{ij} = \min\{V_{ij}, V_{i1}, ..., V_{ij}\}$.
(2) Calculate the Euclidean distance between the target value and the ideal value:
\[
S_i^* = \sqrt{\sum_{j=1}^{m} (V_{ij} - V^*_{ij})^2}, i = 1, 2, ..., m
\] (10)
\[
S_i = \sqrt{\sum_{j=1}^{m} (V_{ij} - V_{ij})^2}, i = 1, 2, ..., m
\] (11)
(3) Calculate the relative closeness degree of each target:
\[
C_i^* = S_i^* / (S_i^* + S_i), i = 1, 2, ..., m.
\] (12)
(4) Sort the target according to the size of the relative closeness degree.
When HW T's $C_i^*$ is closer to the positive ideal solution and farther away from the negative ideal solution, $C_i^*$ is closer to 1. Depending on the size of $C_i^*$, the ranking order of all HWT can be determined and the optimal HWT can be selected.
4. Case analysis
In order to verify the effectiveness and practicability of the model provided in this paper, an example is given to illustrate the application process of evaluation selection in HWT. According to the established indicator system, collect the qualitative indicators of relevant companies and conduct statistical analysis by issuing questionnaires to three industry experts, and determine the fuzzy data of the indicators according to the survey results. The HWT fuzzy evaluation matrix is calculated by formula (1) ~ (2), as shown in Table 2.

By using formula (3), the fuzzy evaluation matrix is transformed into a clear evaluation matrix, as shown in Table 3.

After using formula (4) ~ (5) to normalize the selection matrix data of m&a targets, the grey relational analysis method is used to give weight to the index weight through formula (6) ~ (8), and the weight is shown in Table 4. According to the index weight, the weighted evaluation matrix is calculated by formula (9), as shown in Table 5.

The Euclidean distance between the target value and the positive and negative ideal values is calculated by formula (10) and (11). The results are shown in Table 6 and Table 7.
According to formula (12), and the degree of relative closeness were calculated and sorted.

The results are shown in Table 8.

Table 6. The distance between the target value and the positive ideal value \( (V_o - V'_o) \).

|    | A1    | A2    | A3    | A4    | A5    |
|----|-------|-------|-------|-------|-------|
| PC | 9.45878E-05 | 1.5134E-05 | 0.000242145 | 9.45878E-05 | 0     |
| PSA| 0     | 3.57525E-06 | 0.000804431 | 0.000514836 | 3.21773E-05 |
| WE | 3.18116E-05 | 0     | 0.000127247 | 3.18116E-05 | 1.41385E-05 |
| ST | 0.00078626 | 0.000632688 | 0     | 5.09897E-05 | 0.000465109 |
| QS | 0.000638891 | 0.000110919 | 3.99307E-05 | 0     | 0     |
| F  | 0.000161513 | 5.2739E-05 | 0.000329619 | 0.000161513 | 0     |
| COS| 0     | 9.22709E-05 | 3.69057E-05 | 0.00012631 | 0.00012631 |
| FS | 0.000305355 | 3.39284E-05 | 3.39284E-05 | 0     | 3.76982E-06 |
| HS | 0.000142226 | 3.95072E-06 | 3.55565E-05 | 0     | 1.58029E-05 |
| TCH| 1.79499E-05 | 4.48747E-06 | 0.000542984 | 0.000287198 | 0     |
| EPS| 4.34423E-05 | 0     | 0.000173769 | 4.34423E-05 | 1.93077E-05 |
| RP | 3.96897E-05 | 4.40997E-06 | 0.000357207 | 0.000158759 | 0     |
| OVF| 3.18116E-05 | 0     | 0.000127247 | 3.18116E-05 | 1.41385E-05 |
|    | 0.047890902 | 0.030888552 | 0.053394473 | 0.038746082 | 0.026282177 |

Table 7. The distance between the target value and the negative ideal value \( (V_o - V'_o) \).

|    | A1    | A2    | A3    | A4    | A5    |
|----|-------|-------|-------|-------|-------|
| PC | 9.45878E-05 | 1.5134E-05 | 0.000242145 | 9.45878E-05 | 0     |
| PSA| 0     | 3.57525E-06 | 0.000804431 | 0.000514836 | 3.21773E-05 |
| WE | 3.18116E-05 | 0     | 0.000127247 | 3.18116E-05 | 1.41385E-05 |
| ST | 0.00078626 | 0.000632688 | 0     | 5.09897E-05 | 0.000465109 |
| QS | 0.000638891 | 0.000110919 | 3.99307E-05 | 0     | 0     |
| F  | 0.000161513 | 5.2739E-05 | 0.000329619 | 0.000161513 | 0     |
| COS| 0     | 9.22709E-05 | 3.69057E-05 | 0.00012631 | 0.00012631 |
| FS | 0.000305355 | 3.39284E-05 | 3.39284E-05 | 0     | 3.76982E-06 |
| HS | 0.000142226 | 3.95072E-06 | 3.55565E-05 | 0     | 1.58029E-05 |
| TCH| 1.79499E-05 | 4.48747E-06 | 0.000542984 | 0.000287198 | 0     |
| EPS| 4.34423E-05 | 0     | 0.000173769 | 4.34423E-05 | 1.93077E-05 |
| RP | 3.96897E-05 | 4.40997E-06 | 0.000357207 | 0.000158759 | 0     |
| OVF| 3.18116E-05 | 0     | 0.000127247 | 3.18116E-05 | 1.41385E-05 |
|    | 0.047890902 | 0.030888552 | 0.053394473 | 0.038746082 | 0.026282177 |

According to formula (12), \( S_i^r, S_i^c \) and the degree of relative closeness were calculated and sorted. The results are shown in Table 8.

Table 8. Hazardous waste transporter's \( S_i^r, S_i^c \) and \( C_i^r \).

|    | A1    | A2    | A3    | A4    | A5    |
|----|-------|-------|-------|-------|-------|
| \( S_i^r \) | 0.0485 | 0.0547 | 0.0518 | 0.0611 | 0.0447 |
| \( S_i^c \) | 0.0618 | 0.0658 | 0.0707 | 0.0583 | 0.0677 |
| \( C_i^r \) | 0.5601 | 0.5597 | 0.5772 | 0.4883 | 0.6025 |
| Rank | 2     | 4     | 3     | 5     | 1     |
According to the ranking results, it can be seen that among the five intended enterprises, A5 has the highest degree of relative closeness and is the best target enterprise.

5. Conclusions
The particularity of hazardous waste industry makes the selection of third-party reverse logistics suppliers become important. In reality, there are many factors to be considered when choosing a supplier, and the different importance of each factor and the different preferences of each expert will make the selection difficult. In this paper, from the perspective of waste production unit, combined with the present situation and the property of the waste industry in China, from technology innovation ability and service level, economic level, environment and security, and additional services to establish HWT in five dimensions, evaluation index system of selection, and further through the fuzzy theory to reality the qualitative evaluation, quantitative processing, grey correlation TOPSIS model introduced in many choose the optimal HWT enterprises. Demonstrate that health and safety of HWT services is the primary consideration in the selection process. The new index system in this paper is in line with the reality, and the method used is more scientific and objective, which provides an effective method for studying the evaluation selection of hazardous waste transporters.

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