Advances in Social Science, Education and Humanities Research (ASSEHR), volume 75
2016 International Seminar on Education, Innovation and Economic Management (SEIEM 2016)

# Reverse Logistics Network Design for $SF_6$ in Chinese Electric Power Corporations

Hongqing Zhang[1], Yanfu Zhang[2], Yali Cheng[3]
School of Economics and Management
North China Electric Power University
Beijing, China
bjzhanghongqing@163.com[1], zfy1093@163.com[2], 13051318384@163.com[3]

***Abstract*—Greenhouse gas Sulfur Hexafluoride ($SF_6$) is widely used in Chinese electric power corporations. The corporations need to establish the reverse logistics network for $SF_6$ recovery to reduce greenhouse gas emissions. For managing $SF_6$ waste and filling the research gap from theoretical and empirical research perspective in reverse logistics network design, we designed a comprehensive multi-layer reverse logistics network, including recycle points, recycle/distribution centers, and the $SF_6$ treatment centers. The network was mathematically modeled as a bi-objective and multi-layer fuzzy mixed-integer nonlinear programming model under return quantity uncertainty to minimize the total cost and maximize the comprehensive evaluation values of the $SF_6$ treatment centers. With the cloud model, the method of fuzzy mathematical programming and the interactive non-inferior set estimation method, we obtained the optimal solution which determined transportation quantities of $SF_6$ and the location of facilities. The proposed model was validated by a real world case study, which indicates that the emissions of $SF_6$ will be reduced by 270.23 tons of gaseous $SF_6$.**

***Keywords—$SF_6$; sulfur hexafluoride; reverse logistics network design; electric power corporations; uncertainty; the cloud model***

## I. INTRODUCTION

At present, the $SF_6$ electrical equipment operated for more than 20 years, are in the repairing period, which caused lots of $SF_6$ to be replaced. It greenhouse effect of $SF_6$ is about 23900 times as much as that of $CO_2$. Accordingly, Recycling and reusing $SF_6$ can reduce the adverse greenhouse effect.

In recent years, a host of scholars at home and aboard does research mainly on recycling and processing $SF_6$. Such as J. Zhang, J.Z. Zhou, Q. Liu, G. Qian, and Z.P. Xu demonstrated that the waste electroplating sludge can be potentially used as an effective removal agent for $SF_6$[1]. I. Matito J. Alvarez J. Gutierrez, M. Doblare, A. Martin, and S. Calero stated that zeolites BEC, ITR, IWW, and SFG are regarded as the most promising materials for a nitrogen-sulfur hexafluoride mixture separation[2]. Moreover, electric experts from China presented some views of $SF_6$ recycling. Z. Liu and Y.M. Wang put forward to some suggestions about waste management of $SF_6$, according to the recovery status of $SF_6$ in Inner Mongolia western region[3]. Previous studies have demonstrated that the researches are focused on purging $SF_6$. Correspondingly, there is less study on the management of $SF_6$ recycling in the present, and lack of related experience in the practice field.

Based on the aforementioned considerations, an FMINLP model under risk is presented for mathematically expressing the reverse logistics network for $SF_6$ recycling and reusing in Chinese power grid enterprise. From the subjects, the purpose and innovation of this model was to fill the research gap from the dual—theoretical and empirical research perspective in reverse logistics network design.

## II. STRATEGIC NETWORK DESIGN FOR $SF_6$ RECOVERY IN CHINESE ELECTRIC POWER CORPORATIONS

### A. Problem definition

Based on the provincial forward logistics network, the reverse logistics network for $SF_6$ recovery in Chinese electric power corporations is set up. The network is multi-layer, consisting of recycle spots, recycle/distribution centers and the $SF_6$ treatment centers.

As illustrated in Fig. 1, the proposed network is integrated forward flow and reverse flow. In the reverse flow, local power supply companies collect and store $SF_6$ waste in their own recycle spots. When the $SF_6$ reaches a certain amount, it is shipped to recycle/distribution centers and equivalent and qualified $SF_6$ is taken back from the $SF_6$ treatment center to recycle/distribution centers in the forward flow annually. It is noted that new $SF_6$ from suppliers equals to $SF_6$ waste in the first year. Except the first year, some new $SF_6$ is purchased annually because $SF_6$ waste cannot be completely purified.

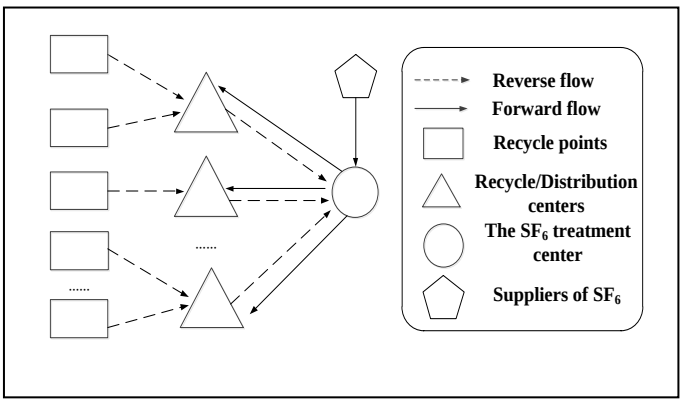


Fig. 1. Reverse logistics network for $SF_6$ recovery in Chinese electric power corporations

One of the objectives of the proposed model is to minimize the total cost of the system including transportation, purchasing, storing, processing and fixed cost. In addition to minimizing total logistic costs, the standards on site selection of the $SF_6$ treatment center are taken into consideration, which made the model built more in line with the actual situation. As a consequence, taken network costs and evaluation values into account, the reverse logistics network is designed.

### B. Model formulation

To support the presentation of the proposed mathematical model, the following notations are used in the formulation of the FMINLP model.

**Sets**

$W$: Fixed set of points for recycle spots, $i \in W.R$: Sets of the candidate points for recycle/distribution centers, $j \in R.P$: Sets of the candidate points for the $SF_6$ treatment centers, $m \in P.Y$: Fixed sets of suppliers of $SF_6$, $b \in Y$.

**Parameters**

$\tilde{A}_i$: Quantities of $SF_6$ waste from recycle point $i$ ($\tilde{A}_i$:is a fuzzy number).$v$: Storage cost per unit of $SF_6$.$t_{ij}$: Transportation cost for a unit of $SF_6$ waste from recycle point $i$ to the recycle/distribution center $j$ per km. $t_{jm}$: Transportation cost for a unit of $SF_6$ waste from recycle/distribution center $j$ to $SF_6$ treatment center m per km. $t_{bm}$: Transportation cost for per unit of new $SF_6$ from supplier $b$ to $SF_6$ treatment center $m$ per km. $d_{ij}$: Distance between recycle point $i$ and recycle/distribution center $j$.$d_{jm}$: Distance between recycle/distribution center $j$ and $SF_6$ treatment center $m$. $d_{bm}$: Distance between supplier $b$ and $SF_6$ treatment center $m$. $J_{min}$: The smallest store capacity in each recycle/distribution center. $J_{max}$: The largest store capacity in each recycle/distribution center. $f$: Fixed cost of opening $SF_6$ treatment center m. $p$: Disposal cost per unit of $SF_6$ waste.$r_0$: Discount rate. $\sigma$: Exhaust gas purification rate.$C$: Purchasing cost per unit of $SF_6$. $E_m$: The comprehensive value of $SF_6$ treatment center m. $T$: Service lives of $SF_6$ treatment center.

**Decision variables**

$x_{ij}$: Quantity of $SF_6$ shipped from recycle point $i$ to recycle/distribution center $j$. $x_{jm}$: Quantity of $SF_6$ shipped from recycle/distribution center $j$ to $SF_6$ treatment center $m$. $x_{bm}$: Quantity of new $SF_6$ shipped from supplier $b$ to $SF_6$ treatment center $m$.

$$S_j = \begin{cases} 1 \ if \ a \text{ recycle/distribution center } j \ is \ selected \\ 0 \text{ otherwise} \end{cases}$$

$$D_m = \begin{cases} 1 \ if \ a \text{ SF6 treatment center } \ is \ opened \ at \ location \ m \\ 0 \text{ otherwise} \end{cases}$$

In terms of the notations, the mathematical formulation of the network is described by the two objective functions followed by the set of constraints.

**Objective function**

$$Min\ O_1 = \sum_{k\in T}\sum_{i\in W}\sum_{j\in Z}\frac{t_{ij}x_{ij}d_{ij}}{(1+r_0)^k} + \sum_{k\in T}\sum_{j\in Z}\sum_{m\in P}\frac{2t_{jm}x_{jm}d_{jm}}{(1+r_0)^k} + \sum_{b\in U}\sum_{m\in P}\frac{t_{bm}x_{bm}d_{bm}}{(1+r_0)} + \sum_{k\in T}\sum_{b\in U}\sum_{m\in P}\frac{t_{bm}x_{bm}(1-\sigma)d_{bm}}{(1+r_0)^k} + \sum_{k\in T}[\frac{v}{(1+r_0)^k}\sum_{i\in W}\sum_{j\in Z}x_{ij}] + \sum_{m\in P}D_m f + \sum_{k\in T}[\frac{p}{(1+r_0)^k}(\sum_{j\in Z}\sum_{m\in P}x_{jm})] + \frac{C(\sum_{i\in W}\sum_{j\in Z}x_{ij})}{(1+r_0)} + \sum_{k\in T}\sum_{j\in Z}\sum_{m\in P}\frac{Cx_{jm}(1-\sigma)}{(1+r_0)^k} \quad (1)$$

The first objective is to minimize the total cost. The costs are comprised of the transportation costs, storage costs in recycle/distribution centers, purchasing costs from supplier, processing costs and fixed costs for the $SF_6$ treatment center.

$$Max\ O_2 = \sum_{m\in P} E_m * D_m \quad (2)$$

**Constraints:**

$$\sum_m D_m = 1, \forall m \in P \quad (3)$$

$$\sum_j x_{ij} = \tilde{A}_i, \forall i \in W \quad (4)$$

$$\sum_i x_{ij} = \sum_m x_{jm} * D_m, \forall j \in R \quad (5)$$

$$\sum_b x_{bm} = \sum_j x_{jm} * D_m, \forall m \in P \quad (6)$$

$$S_j * J_{min} \le \sum_i x_{ij} \le S_j * J_{max}, \forall j \in R \quad (7)$$

$$S_j \in \{0,1\}, \forall j \in R \quad (8)$$

$$D_m \in \{0,1\}, \forall m \in P \quad (9)$$

$$x_{ij} \ge 0, x_{jm} \ge 0, x_{bm} \ge 0 \ \ and\ integer \quad (10)$$

Constraint (3) insures only one $SF_6$ treatment center is selected. Constraint (4) ensures all the $SF_6$ waste is shipped to the recycle/distribution centers. Constraint (5) requires all the $SF_6$ waste is shipped from the recycle/distribution centers to the $SF_6$ treatment center. Constraint (6) stipulates that the new $SF_6$ from supplier should be as big as the quantity of $SF_6$ waste in the first year. Constraint (7) restricts the store capacity of the recycle/distribution centers. Constraint (8) and (9) represents the binary variables. Constraint (10) enforces the non-negativity restriction on the decision variables.

### C. Fuzzy constraint sharpening

Due to the constraint (4) with fuzzy parameter $\tilde{A}_i$ , it makes the FMINLP model be solved difficultly. As in [4] the fuzzy equality is translated into $pos\{\sum_j x_{ij} = \tilde{A}_i\} \ge \lambda$ . $pos\{.\}$ represents the possibility of the event, $\lambda$ represents the given confidence level.

Lemma 1 $\tilde{a}_i = (l_i, m_i, r_i)$ is triangular fuzzy number. For an arbitrary $\lambda(0 \le \lambda \le 1)$ , $pos\{z = \tilde{a}_i\} \ge \lambda$ is true when and only when there is a set of inequalities as follows:

$$\begin{cases} z \ge (1-\lambda)l_i + \lambda m_i \\ z \le (1-\lambda)r_i + \lambda m_i \end{cases} \quad (11)$$

$$\begin{cases} \sum_j x_{ij} \ge (1-\lambda)l_i + \lambda m_i \\ \sum_j x_{ij} \le (1-\lambda)r_i + \lambda m_i \end{cases} \quad (12)$$

The FMINLP model is translated into mixed-integer nonlinear programming (MINLP) model because the constraint (4) is replaced by constraint (12). The MINLP can be settled by the LINGO.

### D. The interactive NISE

The NISE method is a form of the weight sums method, which is applied to resolve bi-objective mathematical programming and generate the Pareto optimal set.

The procedure of the method is presented below[5].

Step1: Solve the singular objective programming problem only including the first objective, we can get point $B(f_1^*, \hat{f}_2)$. $f_1^*$is the optimal value of the first objective, $\hat{f}_2$is obtained by bringing $f_1^*$ into the second objective.

Step2: In the same way, solve the singular objective programming problem only including the second objective, we can get point $A(\hat{f}_1, f_2^*)$.

Step3: The weight coefficients of two objective functions can be gained by the NISE method, which makes bi-objective programming problem be transformed into singular objective programming problem.

By the LINGO, we can obtain point $C(f_1, f_2)$. $f_1$and $f_2$ is optimal solution of the model.

Step4: The decision makers are asked whether they agree to the point C. If the decision makers think that $f_2$ is too large, seeing point C as point A and going back to Step3 to obtain the new weight coefficients. Conversely, regarding point C as point B and going back to Step3.

Eventually, the interactive bi-objective decision model can generate the optimal coordinate solution by interacting to the decision makers until they are satisfied.

## III. Comprehensive evaluation of the $SF_6$ treatment centers using the cloud model-based Approaches

The cloud model is used for evaluating the $SF_6$ treatment centers with the index system for site selection because it can integrate ambiguity with randomness and transform between qualitative concepts and their quantitative expressions, which becomes a new evaluation method for site selection.

### A. Basic concept of the cloud model

Let U be universe of discourse expressed by quantitative digits, and C be a qualitative concept in U. If the definite parameter $x \in U$ is a random occurrence in C, and certainty $\mu(x) \in [0,1]$ of x to C is the random number with steady tendency[6].

$$\mu(x): U \to [0,1] \quad \forall x \in U \quad x \to \mu(x) \tag{13}$$

Then, the distribution of x in U is defined as a cloud and each $(x, \mu(x))$ is named as a cloud drop.

The three digital characteristics of cloud are used to quantitatively reflect feature of the cloud model. Expected value (*Ex*) represents the most representative point of qualitative concept. Entropy (*En*) is determined by both randomness and ambiguity of the concept, which reflects association between randomness and ambiguity, and uncertainty degree of the concept. Hyper Entropy (*He*) is considered as the uncertainty degree of *En*, which represents discrete of sample data.

### B. Normal cloud generators

#### 1) Forward normal cloud generator (CG)

Forward normal cloud generator (CG) is used to generate the cloud drops $(x, \mu(x))$ given the cloud descriptors Cloud *(Ex, En, He)*, which is the transformation from the qualitative knowledge to its quantitative representation. The number of cloud drop is N. Procedure includes following steps:

Step1: The $En_i$ in normal distribution randomly is generated whose expectation is *En* and variance is $He^2$, denoted by $En_i$=*NORM*(*En*,$He^2$) $i \in N$.

Step2: The $x_i$ in normal distribution is randomly generated whose expectation is *Ex* and variance is $En_i$, denoted by $x_i$=NORM(*Ex*, $En_i$) $i \in N$.

Step3: Calculate $\mu_i = e^{-\frac{(x_i - Ex)^2}{2En_i^2}}$ $i \in N$.

Repeat steps 1-3 until N cloud drops satisfy the requirement.

#### 2) Backward cloud generator ($CG^{-1}$)

Given a set of samples, backward cloud generator can transform quantitative values into qualitative concepts given represented by three descriptors of cloud drops Cloud *(Ex, En, He)*. The procedure includes following steps:

Step1: Calculate samples average *Ex*, which is the expectation of the collected data, and calculate sample variance. The number of samples is n.

$$Ex = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{14}$$

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \overline{x})^2 \tag{15}$$

Step2: Calculate *En*.

$$En = \sqrt{\frac{\pi}{2}} \times \frac{1}{n}\sum_{i=1}^{n}|x_i - Ex| \tag{16}$$

Step3: Calculate *He*.

$$He = \sqrt{s^2 - En^2} \tag{17}$$

After gaining the three descriptors of cloud drops Cloud *(Ex, En, He)*, we operate CG so as to get the cloud model graph.

### C. Calculation for comprehensive cloud mode

The comprehensive cloud model is a higher-level cloud model which is generated through combining some cloud models of the same type. The algorithm of comprehensive cloud model without weights is in the following formula.

$$\begin{cases} Ex = \frac{Ex_1En_1 + Ex_2En_2}{En_1 + En_2} \\ En = En_1 + En_2 \\ He = \frac{He_1En_1 + He_2En_2}{En_1 + En_2} \end{cases} \tag{18}$$

Suppose a criterion is composed of n sub-criteria. The cloud models of sub-criteria are $C_1$ *(Ex, En, He)*, $C_2$ *(Ex, En, He)*,…, $C_n$ *(Ex, En, He)*, respectively, and the weight values of each sub-criterion are $v_1, v_2,\ldots,v_n$ respectively. The algorithm of weighted comprehensive cloud model is in the following formula.

$$\begin{cases} Ex = \frac{Ex_1 \times v_1 + Ex_2 \times v_2 + \cdots + Ex_n \times v_n}{v_1 + v_2 + \cdots + v_n} \\ En = \frac{{v_1}^2}{{v_1}^2 + {v_2}^2 + \cdots + {v_n}^2} En_1 + \cdots + \frac{{v_n}^2}{{v_1}^2 + {v_2}^2 + \cdots + {v_n}^2} En_n \\ He = \frac{{v_1}^2}{{v_1}^2 + {v_2}^2 + \cdots + {v_n}^2} He_1 + \cdots + \frac{{v_n}^2}{{v_1}^2 + {v_2}^2 + \cdots + {v_n}^2} He_n \end{cases} \quad (19)$$

In conclusion, qualitative evaluation is described by the cloud model, which can significantly reduce subjective of evaluation. Qualitative concepts can be transformed to quantitative data with the cloud model so that it can improve accuracy of qualitative evaluation and provide objective and accurate standard for the final decision.

## IV. ILLUSTRATIVE EXAMPLE

In the section, a real example for $SF_6$ recovery in Province N, China is presented to demonstrate the validity and applicability of the proposed mathematical model. Province N is composed of nine cities and each of them has a distribution center denoted by $R_1$, $R_2$…$R_9$ in the forward logistics network for electric power materials. Every distribution center is responsible for transporting supplies to the some warehouses in the same region. There are 44 warehouses denoted by $W_1$, $W_2$…$W_{44}$ respectively. Making full use of the existing distribution centers and warehouses, N provincial electric power company planned on taking warehouses as recycle spots and considering distribution center as recycle/distribution centers. All liquefied $SF_6$ waste store in the cylinders to transport. For the sake of simplicity, the assumption is that each cylinder is filled with 50 kg liquefied $SF_6$.

First of all, evaluating $SF_6$ treatment center with the cloud model to acquire the comprehensive value $E_m$. And then, the $E_m$ of each $SF_6$ treatment center is brought into the FMINLP model to resolve transportation quantities of $SF_6$, the location of facilities, maximum evaluation value and minimum total cost.

### A. Comprehensive evaluation of the $SF_6$ treatment centers

#### 1) Index system for site selection of the $SF_6$ treatment centers

Taking the main factors affecting site selection of the $SF_6$ treatment center including natural environment, management environment, and the conditions of infrastructures, environmental protection and so on into consideration, specialists eliminated the index whose values are no significant differences between the three candidates and established the index system for site selection of the $SF_6$ treatment centers. The index system is made up of two criteria including natural environment and the conditions of infrastructures and each criterion is composed by some sub-criteria.

The G1 method is a kind of the subjective weighting method. The weights of index can be acquired through qualitative sorting and rational judgment of importance ratio between the adjacent indices. The index system for site selection of the $SF_6$ treatment centers and corresponding weights are given in Table I. The fundamental principle and steps of G1 method are shown in [7].

TABLE I. THE INDEX SYSTEM FOR SITE SELECTION OF THE $SF_6$ TREATMENT CENTERS AND WEIGHTS

| Criteria | Weights | Sub-criteria | Weights |
|---|---|---|---|
| Natural environment ($V_1$) | 0.4 | The distance between the $SF_6$ treatment center and nearby residents ($V_{11}$) | 0.525 |
| | | Hydrologic condition ($V_{12}$) | 0.15 |
| | | Terrain condition ($V_{13}$) | 0.225 |
| | | Geological condition ($V_{14}$) | 0.1 |
| The conditions of infrastructures ($V_2$) | 0.6 | Communication condition ($V_{21}$) | 0.1667 |
| | | Traffic convenience ($V_{22}$) | 0.5836 |
| | | Power, water, gas, supply capacity and heating capacity ($V_{23}$) | 0.2501 |

#### 2) The determination of evaluation set

The evaluation set is a measure of determining where every candidate stands, which makes every candidate gain the final e valuation. With the model-driven method based on the golden s ection, the evaluation set consists of five ranking grades. The fi ve ranking grades (‘good’, ‘fair’, ‘normal’, ‘low’, ‘lower’) of th e qualitative factors are thus quantitatively expressed by five cl oud models Cloud1(1,0.1031,0.013), Cloud2(0.691,0.064,0.00 8), Cloud3(0.5,0.039,0.005), Cloud4(0.309,0.064,0.008) and Cl oud5(0,0.1031,0.013) respectively. The cloud drops of these cl oud models lies on a 0 to 1 scale.

#### 3) Comprehensive evaluation based on the cloud model

Since index system for site selection of the $SF_6$ treatment centers is constitutive of qualitative indices, specialists gave each qualitative index a score. The score including the highest mark and the lowest mark are made up of interval [60,65), [65,70), [70,75), [75,80), [80,85), [85,90), [90,95) and [95,100]. The specialists selected an interval for grading every qualitative index.

Take evaluating candidate $P_1$ as an example. The 10 specialists gave every sub-criterion an interval as the score with questionnaire and the intervals of score are normalized in the form of sub-interval in [0,1]. Then, the intervals of each sub-criterion are respectively translated into the cloud models of the highest mark and the lowest mark with $CG^{-1}$. On the basis of (18), the cloud models of the highest mark and the lowest mark of each sub-criterion are converted into the comprehensive cloud model of each sub-criterion.

Then, based on the (19), the final cloud model is $P_1$ (0.8452, 0.0503, 0.0096).

The calculations for final cloud model of candidate $P_2$ and $P_3$ are similar to candidate $P_1$ and need not be repeated here. Therefore, the final cloud model of three candidates are $P_1$ (0.8452, 0.0503, 0.0096), $P_2$ (0.8369, 0.0553, 0.0064) and $P_3$ (0.8730, 0.0444, 0.0066).With CG, the final cloud model graph of three candidates can generate by MATLAB, which is given in Fig. 2.

By virtue of the *Ex* best representing the qualitative concept C, the evaluation values $E_m$ of candidate $P_1$, $P_2$ and $P_3$ are 0.8452, 0.8369 and 0.8730.

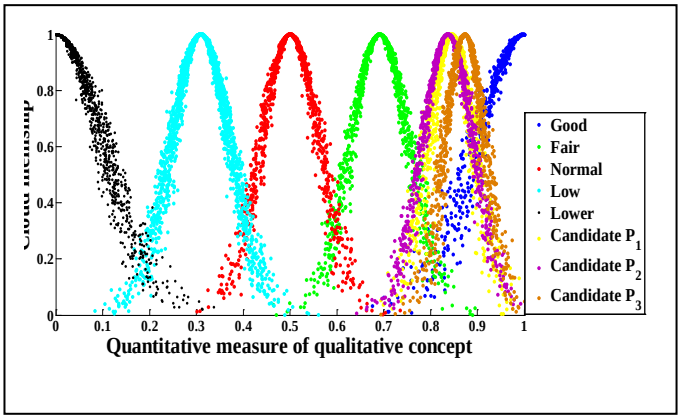


Fig. 2. The cloud model graph of five ranking grades and three candidates

### B. The final decision

Because the average quantities of $SF_6$ waste in each year were estimated by the specialists according to the investigation of various cities and counties, the quantities of $SF_6$ waste are fuzzy and can be replaced by triangular fuzzy number $\tilde{A}_i = (l_i, m_i, r_i)$. $l_i$ and $r_i$ represent minimum and maximum which are might be possible and $m_i$ is the most likely number. The average quantities of $SF_6$ waste are considered as $m_i$. Assuming that fuzzy membership mapped to the fuzzy center number within the scope of 10%, the triangular fuzzy number of $SF_6$ waste can be resolved.

The confidence level was set to 0.2 by the specialists, storage cost $f$ in each recycle/distribution centers is 80 Yuan per cylinder, the fixed cost $f$ for the $SF_6$ treatment center is 5 million Yuan, the processing cost $r_0$ is 2300 Yuan per cylinder, the discount rate $\sigma$ is 10%, the exhaust gas purification rate is 98%, the unit price C of new $SF_6$ is 3400 Yuan per cylinder, and the smallest store capacity $J_{min}$ and the largest store capacity $J_{max}$ in each recycle/distribution center are 15 cylinders and 150 cylinders. The freight rates and distance between facilities are also known.

With the weighted sums, the two different objective functions are synthesized to a normalized objective function. Then, program calculation is conducted on the model by LINGO 12.0 software. $O_{1min}$ is 15594210 and $O_{2min}$ is 0.873.

When the objective function including only $O_1$ , the point B is (1,0.91). When the objective function including only $O_2$, the point A is (1.23,1). Through constantly interacting with decision makers, when two weight coefficients is 0.3 and 0.7 respectively, the total cost of logistics is 15814310 Yuan and the comprehensive evaluation value of the $SF_6$ treatment center is 0.873, decision makers are most satisfied. $R_1$, $R_2$, $R_4$, $R_5$, $R_6$ and $R_9$ are chosen as recycle/distribution centers, $P_3$ is selected as the $SF_6$ treatment center.

As a result, there are 4387 cylinders of $SF_6$ are recycled in the next 10 years. A cylinder of liquefied $SF_6$ approximately equates to 10 cubic meters of gaseous $SF_6$. It means that the emissions of $SF_6$ will be reduced by 270.23 tons of gaseous $SF_6$ which is the equal of 6458497 tons of $CO_2$ (23900×270.23t=6458497t). As can be seen, $SF_6$ recovery has obvious environmental benefit for application.

## V. Conclusion

Taking full advantage of the existing facilities in the forward logistics network for electric power materials, the reverse logistics network for $SF_6$ recovery in Chinese electric power corporations was established, which considered recycle spots, recycle/distribution centers and the $SF_6$ treatment centers. In order to solve the optimal location of facilities and optimal flows in the network, considered fuzzy recycle quantity, a bi-objective and multi-layer FMINLP model was developed for the reverse logistics network. The model integrated minimizing total logistic costs and maximizing the evaluation value as the final objective function.

The proposed reverse logistics network for $SF_6$ recovery provided theoretical and practical basis for Chinese electric power corporations. And it was profitable both in environment and society.

## References

[1] J. Zhang, J.Z. Zhou, Q. Liu, G. Qian, and Z.P. Xu, “Efficient removal of sulfur hexafluoride ($SF_6$) through reacting with recycled electroplating sludge,”. Environ. Sci. Technol. vol. 47, pp. 6493-6499, 2013.

[2] I. Matito J. Alvarez J. Gutierrez, M. Doblare, A. Martin, and S. Calero, “Zeolites for the selective adsorption of sulfur hexafluoride,”. Phys. Chem. Chem. Phys. vol. 17, pp. 18121-18130, 2015.

[3] Z. Liu and Y.M. Wang, “Analysis of sulfur hexafluoride recovery,”. Inner Mongolia Petrochemical Ind., vol.1, pp:42-43. (In Chinese)

[4] B.D. Liu, R.Q. Zhao, and G. Wang, Uncertain programming with applications, CN: Tsinghua University Press, 2003. (In Chinese)

[5] Q.M. Wu, and Q. Jin, “Problems in the application of weighting method to nonliear multiobjective programming,”. J. HEHAI Univ. vol. 16, pp. 94-103 1988. (In Chinese)

[6] Z. Liu, J. Shao, W. Xu, and F. Xu, “Comprehensive stability evaluation of rock slope using the cloud Model-Based approach,”. Rock Mech. Rock Eng. vol. 47, pp. 2239-2252, 2014.

[7] Y. Liu, and L. Qu, “The evaluation model of bank's assets quality based on G1 and Mean-Square deviation methods and its empirical research,”IEEE Commun. Comput. Inf. Sci. China, pp. 243-249, Aug 2011.