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Fuzzy bicriteria multi-index transportation problems for coal allocation planning of Taipower [1]

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Abstract

Taipower, the official electricity authority of Taiwan, encounters several difficulties in planning annual coal purchase and allocation schedule, e.g., with multiple sources, multiple destinations, multiple coal types, different shipping vessels, and even in uncertain demand and supply. In this study, these concerns are formulated as a fuzzy bicriteria multi-index transportation problem. Furthermore, an effective and interactive algorithm is proposed which combines reducing index method and interactive fuzzy multi-objective linear programming technique to cope with a complicated problem which may be prevalent in other industries. Results obtained in this study clearly demonstrate that this model can not only satisfy more of the actual requirements of the integral system but also offer more information to the decision makers (DMs) for reference in favor of exalting decision making quality.

Keywords: Fuzzy set; Fuzzy multi-objective linear programming; Multi-index transportation problems; Coal allocation

1. Introduction

Taiwan Power Company (Taipower) annually imports fourteen million tons of coal from twentyfive coal mining areas in South America, Australia, South Africa, and Indonesia. Next, the coal is transported to ports in Kaohsiung, Taichung, and Keelung by ship and is allocated to each of the power plants on the island. In regard to the limits of ports, different kinds of vessels are required for the ocean transportation and four diverse modes of coal are used because the power plant needs. On the other hand, in the annual reviewed contract, Taipower holds permission of 10% flexible adjustment of delivery amount with coal source, and is the desirable demand of each power plant approximately estimated by the past record and experience. Hence, for some unpredictable situations, the amount of annual supply and demand is naturally vague and uncertain, as well as it is defined as fuzzy number. Therefore, the allocation system of coal even more complicated and difficult. The imported coal for the entire year must be allocated to each month and each importing port in order to meet the requirements of a stable, safe,

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lowcost supply. In another respect, a highly efficient decision system which accommodates actual situations should be set up so that the supply of coal can be at the precise time, in correct quality, and of valid amount.

Tzeng (1985) has established the integral model of coal transportation system of Taiwan. The objective function of this model is minimum cost and also includes the transportation costs on land and in shipment. This model was briefly introduced in its construction but is lacking substantiation. Tzeng and Chow (1986) proposed the notion of network programming for finding out the optimal importing port location of coal for each of the power plants, utilized transportation mode, as well as allocation routes. Accommodating the required amount of coal for each of the power plants in the future is the primary objective of this study.

Fuzzy set theory was proposed by L.A. Zadeh (1965), and has been found extensive in various fields. Bellman and Zadeh (1970) were the first to consider the application of the fuzzy set theory in solving optimization problems. When considering optimization problems in a fuzzy environment, these investigators contended that both the objective functions and the constraints that exist in the model could be represented by corresponding fuzzy sets and should be treated in the same manner. The earliest applications of it to transportation problems include Prade (1980), O'he'igeartaigh (1982), Chanas et al. (1984), Verdegay (1984) and Delgado et al. (1987). But these researcher emphases on investigating theory and algorithm. Furthermore, these above investigations are illustrated with simple instances, lacking in actual cases for substantiation. On the other hand, these models are only of single objective and are classical two index transportation problems.

In actual transportation problems, the multi-objective functions are generally considered, which includes average delivery time of the commodities, minimum cost, etc. The first attempt to fuzzify a linear programming with multiple objective functions was made by Zeleny (1973). Zimmermann (1978) applied the fuzzy set theory to the linear multicriteria decision making problem. It used the linear fuzzy membership function and presented the application of fuzzy linear programming approaches to the linear vector maximum problem. He showed that solutions obtained by fuzzy linear programming always provide efficient solutions and also an optimal compromised solution. Aneja and Nair (1979) presented bicriteria transportation problem model and Klingman and Phillips (1988) developed a model/solution procedure for adjusting to obtain an equitably infeasible solution for an infeasible transportation problem. Klingman and Phillips (1988) showed that the problem can be modeled and solved as a preemptive, multicriteria, and capacitated transportation problem.

Multi-index transportation problems are the extension of conventional transportation problems, and are appropriate for solving transportation problems with multiple supply points, multiple demand points as well as problems using diverse modes of transportation demands or delivering different kinds of merchandises. Thus, the forwarded problem would be more complicated than conventional transportation problems. Junginger (1993) who proposed a set of logic problems to solve multi-index transportation problems, has also conducted a detailed investigation regarding the characteristics of multi-index transportation problem model. Rautman et al. (1993) used multi-index transportation problem model to solve the shipping scheduling suggested that the employment of such transportation problems model would not only enhance the entire transportation efficiency but also optimize the integral system. These references are only a single objective model and its constraints are not fuzzy numbers.

In this study, a model is developed, and it combines fuzzy multi-objective programming and multi-index transportation problems to solve an actual case for coal allocation planning of Taipower. This model can not only satisfy more of the actual requirements of the integral system but is also more flexible than conventional transportation problems. Furthermore, it can offer more information to the decision maker (DM) for reference, and then it can raise the quality for decision making. The fuzzy multi-objective multi-index transportation problem model is presented in Section 2. Section 3 describes the background of the problem of Taipower as well as presents the formulation of problem. Section 4 shows the procedure of solution. Results and discussions are proposed in Section 5. Concluding remarks are finally made in Section 6.

2. Fuzzy multiobjective multi-index transportation problem

The well-known transportation problem (Hitchcock, 1941)) is a specific problem of resource allocation and can be formulated as a linear programming problem where constraints have a special structure. In its classical form, the transportation problems minimizes the cost of transporting some commodities that are available at m sources (supply nodes) and required at n destinations (demand nodes). If the amount of supply nodes or demand nodes is a fuzzy number, the basic transportation problems with fuzzy constraints can be represented as single objective fuzzy transportation problems.

$$\text{Minimize } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij} X_{ij} \tag{1}$$

subject to

$$\sum_{j=1}^{n} X_{ij} \cong \tilde{S}_i, \quad i = 1, \dots, m, \tag{2}$$

$$\sum_{i=1}^{m} X_{ij} \cong \tilde{D}_j, \quad j = 1, \dots, n, \tag{3}$$

$$X_{ij} \geq 0, \quad i = 1,2, \dots, m, \; j = 1,2, \dots, n, \tag{4}$$

where X_{ij} represents the amount of commodity to be shipped from source i to destination j. C_{ij} is the cost of transporting a unit from source i to destination j. $\tilde{S}_i$ and $\tilde{D}_j$ represent the availability at source i and the requirement at destination j. Both of these amounts are fuzzy numbers. Symbol "$\cong$" denotes "approximately equal".

In practical application, however, multiple objective functions are normally considered. These objectives are frequently in conflict. Examples of additional concerns include: average delivery time of the commodities, reliability of transportation, accessibility to the users, among others. These types of fuzzy transportation problems are multiobjective in nature and, therefore, can be formulated as fuzzy multiobjective transportation problem.

$$\text{Minimize } Z_k = \sum_{i=1}^{m} \sum_{j=1}^{n} C_{ij}^k X_{ij}, \quad k = 1,2, \dots, K, \tag{5}$$

subject to

$$\sum_{j=1}^{n} X_{ij} \cong \tilde{S}_i, \quad i = 1,2, \dots, m, \tag{6}$$

$$\sum_{x=1}^{m} X_{ij} \cong \tilde{D}_j, \quad j = 1,2, \dots, n, \tag{7}$$

$$X_{ij} \geq 0, \quad i = 1,2, \dots, m, \; j = 1,2, \dots, n, \tag{8}$$

where C_{ij}^k is the cost associated with transporting a unit of the commodity from source i to destination j according to the k's criterion. Replacing the variables X_{ij} by multiple subscript variables $X_{ijhl\dots}$ will change this problem to a fuzzy multi-objective multi-index transportation problem. For instance, if subscript variable has four indices, this occurrence is a problem of shipping a several types of commodity from several supply nodes to several demand nodes by the different kinds of vehicle. If we consider bicriteria function, it can be represented as fuzzy bicriteria four-index transportation problem.

$$\text{Minimize } Z_k = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{h=1}^{o} \sum_{l=1}^{p} C_{ijhl}^k X_{ijhl}, \quad k = 1,2 \tag{9}$$

subject to

$$\sum_{j=1}^{n} \sum_{l=1}^{p} X_{ijhl} \cong \tilde{S}_{ih}, \quad \forall\, i, h \tag{10}$$

$$\sum_{i=1}^{m} \sum_{h=1}^{o} X_{ijhl} \cong \tilde{D}_{jl}, \quad \forall\, j, l \tag{11}$$

$$X_{ijhl} \geq 0, \quad i = 1,2, \dots, m; \; j = 1,2, \dots, n; \; h = 1,2, \dots, o; \; l = 1,2, \dots, p \tag{12}$$

where h and l are the indices of the types of commodities and the kinds of vehicles, respectively.

This model is then applied to coal allocation planning and the method of interactive fuzzy multi-objective linear programming is utilized to solve this problem. As for the fuzzy multi-objective linear programming resolution, it is iterative for a solution that is investigated to improve the flexibility and robustness of multiobjective decision making techniques (Lai and Hwang, 1994). The reason for this is that this method accommodates more to the decision making procedures of the DM. Studies of this kind include Hamacher et al. (1978), Sakawa (1983, 1993), Sakawa and Yano (1988, 1990), Werners (1987a, b), Shin and Ravindran (1991), Climaco et al. (1993) and Lai and Hwang (1992, 1993). Lai and Hwang (1994) presented a practical modeling method which is a symmetric integration of Zimmermann's, Werners's, Verdegay's and Chanas's fuzzy linear programming approaches and provides a decision support system for solving a specific domain of practical linear programming problem. Sakawa (1993) constructed an interactive algorithm in order to solve fuzzy multi-objective programming. It can be interpreted as the fuzzy version of the reference point method with trade-off information. This technique is used in this paper to solve the coal allocation problem.

3. Application in coal allocation planning for Taipower

Taipower must annually import fourteen million tons of coal shipped by oceangoing vessels. The

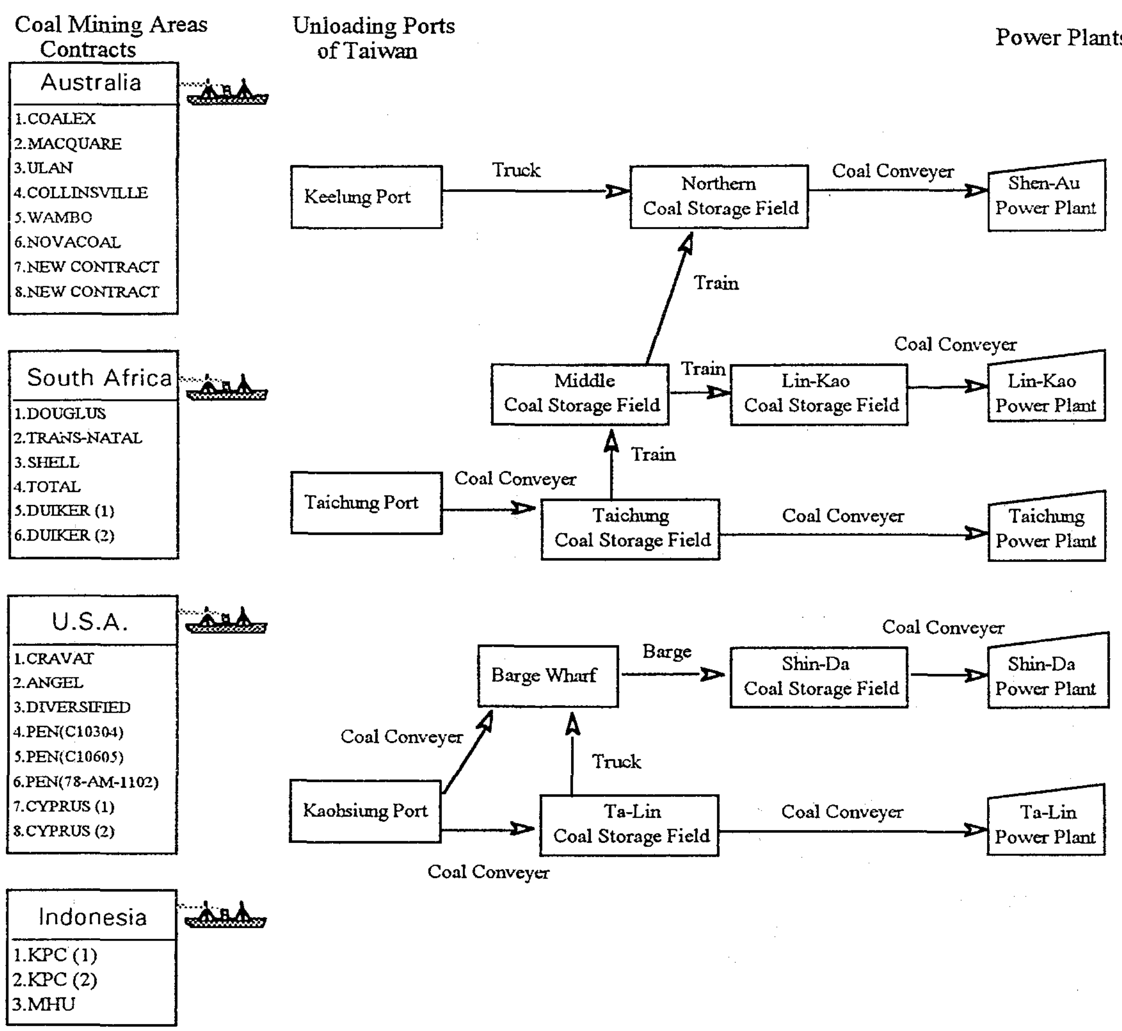

Fig. 1. The systems of coal storage and transportation of Taipower.

sources of these coal mining areas include the United States, South Africa, Australia, Indonesia and other areas. Once such coal is imported to Taiwan through Kaohsiung, Taichung, and Keelung three ports, the bulk of coal will be transported to every power plant for electricity generation.

3.1. Background of the problem

Taipower has five thermal power plants using coal, and its sources of coal supply include countries such as Australia, South Africa, the United States, and Indonesia. On the whole, the coal distribution and transportation system are illustrated in Fig. 1, and the system is composed of three subsystems: ocean transportation subsystem, inland transportation subsystem, and coal storage plant subsystem. The imported coal is first delivered from ports near the coal mining areas by coal transportation vessel to Keelung, Taichung, and Kaohsiung of Taiwan, which is an ocean transportation subsystem. As for an inland transportation subsystem, the conveying belt is used for short distance transportation, while trucks and trains are used to send coal to the deposit field for the utilization of each power plant in medium and longer distance transportation. During the process of transportation, the middle coal storage field and a part of Ta-Lin coal storage field will act as the commuting coal field; in addition, each of the power plants has their own coal deposit field, which is the coal storage field subsystem.

The imported coal will primarily supply nearby power plants. Keelung port will unload less coal because of its heavy operation loading and limits of draft, while the Ta-Lin pier of Kaohsiung port and Taichung port notably take up the burden of unloading coal. Shen Au power plant relied on the imported coal from Taichung port and Keelung port. A small amount of coal required for Lin-Kao power plant is provided by the coal produced in Taiwan, and the rest is primarily supplied by the imported coal from Taichung. The imported coal will be conveyed to Lin-Kao and Shen Au power plants for utilization by train after it is delivered to the central coal deposit field by train when it comes through Taichung. Taichung power plants rely on the imported coal from Taichung port. Ta-Lin and Shin-Da power plants rely on the Ta-Lin special pier; one route will take the coal to Ta-Lin coal field, then the conveying belt will send the coal to Ta-Lin power plant or to Ta-Lin barge pier. The other route takes the coal to the barge pier straight and the barge will deliver the coal to Shin-Da power plant or the conveying belt delivers to Shin-Da power plant.

Since the original design of generators of the each power plant is different, they require different qualities of coal. Among these types of coal, there are various qualities of coal (A, B, C, D) as they come from different places. Therefore, each power plant will be using different types of coal. In addition, due to the constraints of loading and unloading, diverse types must be used in order for transportation. On the other hand, since the annual supply amount (invoiced amount for transportation stipulated in the contract) from the coal source and the monthly imported coal amount (required quantity for every power plant) are an approximate values (fuzzy values). Thus, it makes the allocation system of coal complicated and difficult.

Currently, vessels for hire are classified into three kinds according to their capacity: (1) Handysize; (2) Panamax; (3) Capesize. Since Taipower has no fleet of its own and it employs, at the time, voyage charters to hire vessels to import coal for it. These vessels deliver coal to Taiwan from the loading ports by sea. Primarily, a long term contract has been signed to stipulate a transportation agreement or the fashion of spot charters is selected to deliver. Taipower would, according to the contract, provide sufficient merchandise, and pay the shipping company the multiplied result of the transported amount of coal to the transportation price.

In regard to the constraints of ports, Keelung port is suitable to accept Handysize as of its draft constraint; Taichung can take any kind of vessel aside that of Capesize, while Kaohsiung is capable of receiving these three kinds of vessels. In order to cope with the facilities of coal importing port, amount of coal supply, the demand and supply of shipping tonnage on the maritime market, and unloading requirements of domestic port, the chartered vessels of Taipower are mostly of Panamax and Capesize.

3.2. Problem formulation

Coal allocation model is the combination of fuzzy multi-objective programming and multi-index transportation problems model. The objective functions are: (a) minimize the total cost of freight for importing coal and (b) maximize satisfaction level of overall schedule pattern. The constraint equations will consider the requirements of coal qualities and consumption amount, the invoiced annual amount for transportation and coal qualities contracted from the coal mining areas, and the constraints of loading and unloading ports as well as the limits of vessel type of each power plant. It is through such model that the monthly amount of transportation from coal mining areas to each unloading port is derived. Mathematical equations for coal allocation model are shown in the following.

3.2.1. Definitions

- $i = 1, \ldots, 23$, coal sources;
- $j = 1, \ldots, 3$, unloading ports of Taiwan; $j = 1$: Kaohsiung, $j = 2$: Taichung, $j = 3$: Keelung;
- $h = 1, \ldots, 3$, types of vessels; $h = 1$: Capasize, $h = 2$: Panamax, $h = 3$: Handysize;
- $l = 1, \ldots, 12$, months,
- $q = 1, \ldots, 4$, types of coal qualities; $q = 1$: type A, $q = 2$: type B, $q = 3$: type C, $q = 4$: type D;
- $k = 1, 2$, objective function; $k = 1$: total shipping cost, $k = 2$: satisfaction level of overall schedule pattern;
- $\tilde{S}_{iq}$ = the annually q coal supply of source i (fuzzy numbers; unit: thousand ton);
- $\tilde{D}_{jlq}$ = the q coal demand of unloading port j at 1 month (fuzzy numbers; unit: thousand ton);
- C_{ijh}^{lq} = the freight of coal shipped from source i to unloading port j by ship type h (unit: \$/thousand ton);
- X_{ijh}^{lq} = the amount of coal shipped from source i to unloading port j by ship type h at 1 month (unit: thousand ton).

3.2.2. Fuzzy parameters

The annual amount of supply from the coal sources and the monthly demand of each power plant are fuzzy numbers. Therefore, the membership function must be constructed before the model of solution is set up. For the membership function of supply, it is stipulated in the long term coal supply contract that the actual transportation amount cannot match with the one set down in the contract, the amount can be adjusted flexibly within the margin of ten percent

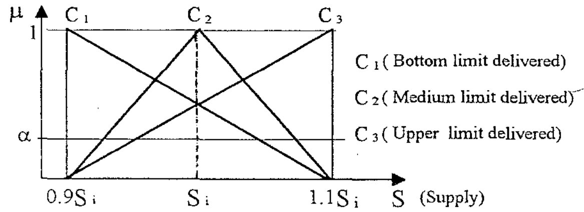

Fig. 2. Fuzzy numbers of supply (S_i denotes i's coal sources).

more or less in accordance to the stipulated quantity. Additionally, a heavy penalty is set down for any violation of this stipulated domains. Therefore, DMs, in their decision making, would mostly target at their lower cost coal supply invoiced for transportation to its upper limit and plan, at best, for 110 percent invoiced amount to the stipulated supply written in the contract so as to minimize transportation costs, and vice versa. As for the medium range transportation costs, they are settled according to the contract stipulation. As a result, the membership function of supply would include three different kinds, i.e., 1. bottom limit delivered (C_1); 2. medium limit delivered (C_2); 3. upper limit delivered (C_3), as indicated in Fig. 2.

The μ represents degree of satisfaction of DMs and α denotes the α level cut. The α-level set of a fuzzy set A is defined as an ordinary set A_α for which the degree of its membership function exceeds the level α:

$$A_\alpha = \{x | \mu_A(x) \geq \alpha\}, \alpha \in [0, 1] \tag{13}$$

the membership functions of supply are as follows:

$$\mu_{C_1}(S) = \begin{cases} 0, & S < 0.9S_i \text{ or } S > 1.1S_i \\ 5.5 - \dfrac{5S}{S_i}, & 0.9S_i \leq S \leq 1.1S_i \end{cases} \tag{14}$$

$$\mu_{C_2}(S) = \begin{cases} 1, & S = S_i \\ \dfrac{10S}{S_i} - 9, & 0.9S_i \leq S < S_i \\ 11 - \dfrac{10S}{S_i}, & S_i < 1.1S_i \\ 0, & S < 0.9S_i \text{ or } S > 1.1S_i \end{cases} \tag{15}$$

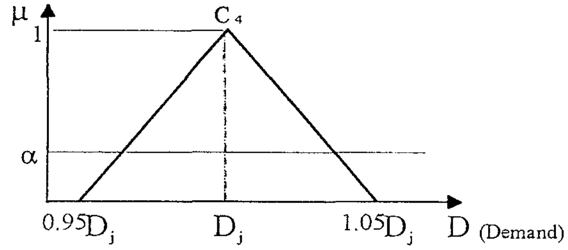

Fig. 3. Fuzzy numbers of demand (D_j denotes j's demand nodes).

$$\mu_{C_3}(S)=\begin{cases}0, & S<0.9S_i \text{ or } S>1.1S_i\\ \dfrac{5S}{S_i}-4.5, & 0.9S_i\le S\le 1.1S_i\end{cases} \tag{16}$$

where S_i is i's coal sources

The monthly quantity of demand of generators in each power plant can be predicted from the monthly consumption amount by each power plant in the past, and an approximate value can be obtained. Since every power plant has its coal storage field for flexible adjustment, its fuzzy numbers shown in Fig. 3 have been obtained from interviewing DMs.

This membership function is as follows:

$$\mu_{C_4}(D)=\begin{cases}1, & D=D_j\\ \dfrac{20D}{D_j}-19, & 0.95D_j\le D<D_j\\ 21-\dfrac{20D}{D_j}, & D_j<D\le 1.05D_j\\ 0, & D<0.95D_j \text{ or } D>1.05D_j\end{cases} \tag{17}$$

3.2.3. Objective functions

1. Minimal total shipping costs for the year.

$$\text{Minimize } Z_1=\sum_q\sum_i\sum_j\sum_h\sum_l C_{ijh}^{lq}X_{ijh}^{lq} \tag{18}$$

2. Maximal satisfaction level of overall schedule pattern

$$\text{Maximize } Z_2=\mu(U) \tag{19}$$

The second objective represents DM's satisfaction degree of the overall schedule pattern. For linguistic ambiguity of "satisfaction", it is formulated as fuzzy satisfaction objective where $\mu(U)$ denotes fuzzy objective of satisfaction of scheduling pattern and U denotes scheduling pattern. In a practical situation, the DMs generally prefer a schedule of average scattering pattern, i.e., successive delivery schedule should be avoided as much as possible.

Table 1 illustrates the scheduling pattern which DMs prefers, where no successive delivery occurs. When the allocation scheduling can be more average distributed to each month, the DMs are more satisfied. On the contrary, the DMs may resist that of successive delivery.

3.2.4. Constraints

1. Constraint of invoiced amount for transportation from the long term coal sources:

$$\sum_j\sum_h\sum_l X_{ijh}^{lq}\cong\tilde{S}_{iq},\quad \forall i,q \tag{20}$$

possible shapes of fuzzy numbers $\tilde{S}_{iq}$ are shown in Fig. 2.

2. Constraint of monthly demand of each unloading port:

$$\sum_i\sum_h X_{ijh}^{lq}\cong\tilde{D}_{jlq},\quad \forall j,q,l \tag{21}$$

Table 1
The scheduling pattern of DM satisfies. Unit: thousand ton

Source	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
COALEX	108.4				93.2			56.8				48.9
ULAN			96.8			69.4			102.4			
WAMBO	68.9			105.3			64.5				105.6	
TOTAL		78.4				110.0		47.8		58.9		89.0
PEN			68.7		78.4			79.0			70.2	

possible shapes of fuzzy numbers $\tilde{D}_{jlq}$ are shown in Fig. 3.

3. Constraint of vessel: Due to the constraint of draft in some coal loading piers it is, therefore, some types of vessels are not suitable and so the transportation amount X_{ijh}^{lq} of this combination is designated at zero.

4. Constraint of vessel to the coal unloading port: Because of the constraint of draft for vessel, Taichung can only accept Panamax size and Handy size vessels. Keelung can only accept the Handy size and Kaohsiung can take these three kinds of vessels. Thus, the transportation amount of these constraint combination is set at zero.

5. Constraint of supply capacity of the coal loading port: Due to the constraint of supply capacity from the port of coal supply, the invoiced amount for transportation would not exceed the capacity of one Cape size (110 thousand tones capacity) or two Panamax (114 thousand tones capacity) in the same month and same coal supply. Additionally, this model employs 110 thousand tones capacity as its constraint amount.

$$\sum_j \sum_h X_{ijh}^{lq} \le 110, \quad \forall i, l \tag{22}$$

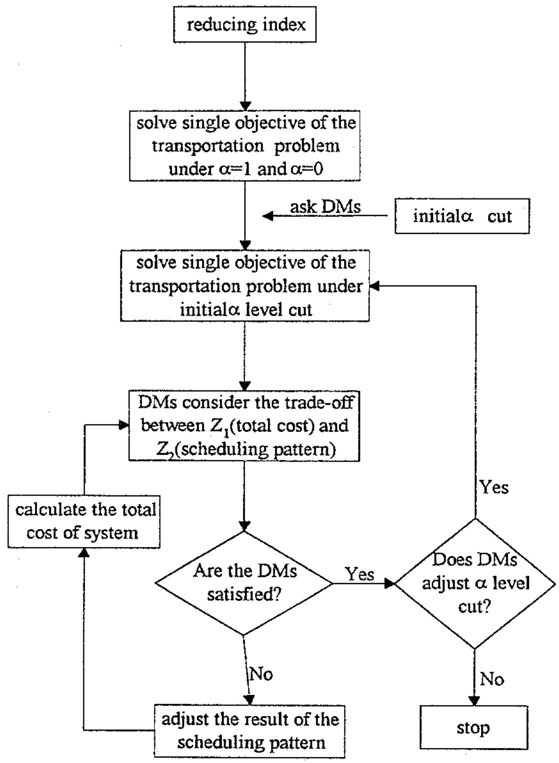

Fig. 4. The flowchart of solution.

4. The procedure of solution

Since there are too many model indices and the system is overwhelming, locating its solution is quit difficult. Therefore, reducing index method and interactive fuzzy multi-objective linear programming method are used in this study to solve it. The processes of solution finding are divided into two stages, as shown in Fig. 4 and elaborated in the following:

First Stage: reducing index stage

Since each kind of coal is produced from various sources and coal transportation vessel carries only a kind of coal; thus, the index of the coal type is selected to be a reducing index. The entire allocation system is separated into four different kinds of coal subsystems for resolution. In these four subsystems, the importing port index and monthly index are further combined into one, that is, the index of the demand of the three ports are divided into thirtysix index of the demand. As a result, the model would

Table 2
Adjust the outcome result pattern. Unit: thousand ton

Source	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.
COALEX	108.4				93.2	56.8**A**			**A′**			48.9
ULAN			96.8			**B′**		69.4	102.4**B**			
WAMBO	**C′**			105.3			64.5	68.9**C**			105.6	
TOTAL	47.8**D**	78.4				110.0		**D′**		58.9		89.0
PEN			68.7		78.4			79.0			70.2	

be left as fuzzy transportation problems of only three indices (supply, demand and vessel types indices).

Second Stage: solution stage for fuzzy bicriteria transportation problems

In this stage, the interactive fuzzy multi-objective linear programming with fuzzy parameters concept (Sakawa (1993)) is applied to solve each subsystem. Since the second objective is a fuzzy objective of satisfaction of outcome scheduling pattern, DMs will adjust the results to the processes of solution. The principle of adjustment is shown as follows: Table 2 shows the scheduling pattern while single objective (minimum cost) achieved ($\alpha = 1$). For some successive delivery (this situation will make DMs feel reluctant to accept), our algorithm permits DMs to adjust the results according to the following principles: first, select two pairs of coal sources that DMs feel unpleasant (example: A–B pair and C–D pair). Then, select one candidate among delivery schedules through the year, respectively, and exchange the position of the two candidates to counterpart month. (Example: $A \to A'$, $B \to B'$, $C \to C'$, and $D \to D'$). For the characteristics of transportation problems, such an adjustment may lead to the following argument:

1. Increase total cost of system.
2. Violate demand constraint.

Argument 1 is somewhat reasonable because of the trade-off of two objectives. Argument 2 can be explained in two manners: if the forward moving candidate is of a higher delivery amount than that of the backward one, only the storage amount of the power plant increases; in contrast, the adjustment is accepted only if the difference is less than 20 thousand tons, since the difference will be compensated by the current deposit; DMs must determine another pair.

The principle of adjustment has been described and the algorithm of this stage is shown as follows:

Step 0: Individual minimum and maximum

Calculate the individual minimum and maximum of each objective function under the given constraints for $\alpha = 0$ and $\alpha = 1$. In this case, the first objective of the transportation problems is solved under the constraints for $\alpha = 0$ and $\alpha = 1$.

Step 1: Initialization

Ask the DM to select the initial value of α $(0 \le \alpha \le 1)$ and the initial reference levels.

Step 2: α-Pareto optimal solution

For the degree α and the reference levels specified by the DMs, solve the single objective Z_1 (total cost) of the transportation problems under initial a level cut. Next, the DMs consider the trade-off between Z_1 (total cost) and Z_2 (satisfaction of scheduling pattern). If DMs are satisfied with the result of the outcome, this solution is referred to as α-Pareto optimal solution; otherwise, DMs adjust the results of the scheduling pattern.

Step 3: Termination and updating

The DMs is supplied with the corresponding α-Pareto optimal solution and the trade-off rates between the objective functions and the degree α. If the DM is satisfied with the current objective function values of the α-Pareto optimal solution, stop. Otherwise, the DM must update the reference levels and/or the degree α by considering the current values of the objective functions and α together with the trade-off rates between the objective functions and the degree α and return to step 2.

As indicated in the membership function constructed in the former section, the domains of each crisp demand and supply are located under different a and the solution is then solved by using simplex method after such values are added to the constraint equations of the model. Therefore, using interactive fuzzy multi-objective linear programming with fuzzy parameters technique to solve every subsystem model and the solution derived will be assessed by the DMs to observe whether it meets actual situations.

5. Result and discussion

The costs of each type of coal under different α (single objective Z_1; bicriteria Z_1 and Z_2) are illustrated in Tables 3 and 4.

During the solving process of the system, the coal supply of lower transportation cost will be first allocated before that of a higher transportation cost so that the total cost of the system can be reduced. Therefore, when α-cut is smaller, the range of coal supply will be greater and the demand for the coal supply of a comparatively lower transportation cost will increase. Consequently, the entire cost of the system will be lowered as the demand diminishes.

Table 3
The total cost of each type of coal under different α (single objective Z_1). ($/ton)

α-cut	Type A	Type B	Type C	Type D	Total
0.1	37295.24	50814.99	30535.49	23194.53	141840.25
0.2	37490.54	50912.16	30842.04	23223.81	142468.55
0.3	37685.77	51010.02	31148.58	23253.05	143097.42
0.4	37881.03	51107.88	31455.12	23308.74	143752.77
0.5	38076.29	51205.73	31761.66	23411.37	144455.05
0.6	38271.56	51303.59	32068.23	23514.01	145157.39
0.7	*	51401.45	32374.74	23641.02	*
0.8	*	51499.31	32681.29	23773.21	*
0.9	*	51597.17	32987.83	23892.31	*
1.0	*	51695.03	33294.37	24043.75	*

* unfeasible solution

With the situation of different kinds of demands, when the system is to solve, it will select the one with less demand so as to reduce the system objective value to the lowest. Thus, when α-cut value is smaller under diverse α-cut, the range of coal supply will be greater and system objective value will be reduced as the one with less demand can be employed to resolve. The situation can be indicated from the total demand revealed in the table. Furthermore, when α-cut is smaller, the total demand will be less.

Unfeasible solutions occur at the situation in which the amount of supply is smaller than that of demand. This situation arises since the membership function of type A and type D is the bottom limit of invoiced transportation.

Table 4
The total cost (Z_1) of each type of coal under different α-cut when Z_2 is "satisfaction" level (Bicriteria Z_1 and Z_2) ($/ton)

α-cut	Type A	Type B	Type C	Type D	Total
0.1	37335.04	50875.24	30685.68	23231.45	142127.41
0.2	37490.54	50983.25	30870.39	23274.54	142618.72
0.3	37984.72	51007.89	31222.98	23301.45	143517.04
0.4	38172.14	51189.65	31604.13	23376.31	144342.23
0.5	38344.64	51296.54	31821.29	23488.65	144951.12
0.6	38823.58	51378.56	32157.48	23579.32	145938.94
0.7	*	51478.96	32420.03	23716.59	*
0.8	*	51534.89	32786.61	24256.06	*
0.9	*	51652.36	33175.80	24530.42	*
1.0	*	51746.82	33330.71	24883.47	*

* unfeasible solution

6. Conclusions

The following conclusions can be made on the basis of above discussion:

1. The coal allocation system of Taipower is a problem with two objectives, multiple supply points, multiple demands points and a problem using different kinds of vessels to deliver various types of coal. The fuzzy bicriteria objective multi-index transportation problems model is appropriate for satisfying the requirements the actual situations of the allocation.
2. Since the amounts of supply and demand are of approximate values, the results obtained from the utilization of fuzzy theory, interactive programming method and different α-cut can offer DMs more information which can satisfy more DMs.
3. The problem involving the overwhelming size of the system is quite difficult to solve. This study has utilized reducing index method and interactive fuzzy multi-objective linear programming method to locate the solution, which, aside from eliminating the difficulty associated with the system resolution, can allow the DMs to quickly grasp information offered by the system and, ultimately, elevate the quality and efficiency of decision making.
4. The total cost of the year solved from different a level cut, when compared with the transportation expense budget of the year, is found with the slightest difference to the satisfactory solution of the DM. This satisfactory solution is the allocation amount of imported coal to be delivered as it is close to the budget of transportation expense for the entire year.

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