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COMPARING AHP/GRA WITH DEA TO EVALUATE THE PERFORMANCE OF MUNICIPAL WASTE RECYCLING IN TAIWAN

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Summary: *Grey relational analysis (GRA) first proposed by Deng (1986), is an evaluation that focused on few samples and uncertainty conditions. Data Envelopment Analysis (DEA) original proposed by Charnes et al. (1978) to evaluate the relative efficiency of each Decision Making Unit (DMU) with multiple input and output variables. These two methods have popular employed to measure the performance of DMUs by some decision variables on a ratio scale. In this study we apply Analytic Hierarchy Process with Grey Relation Analysis (AHP/GRA) to evaluate the performance of Municipal Solid Waste (MSW) recycling and treatment in Taiwan. Furthermore, we compare the result with DEA model, and conclude the high correlation on the ranking of decision making units. In addition, it seems that AHP/GRA model is appropriate to meet the nature of uncertainty in real world problems.*

Keywords: Municipal Solid Waste, Analytic Hierarchy Process, Grey Relation Analysis, Data Envelopment Analysis, Decision Making Unit

1. Introduction

Along with technological and economic development, mass production has resulted in increasing waste, including hazardous emissions and toxic waste from manufacturing process. According to the Environmental Protection Agency statistics of the United States of America in 2000, over 400 million tons of hazardous waste emissions and industrial waste is processed annually worldwide. Furthermore, about 480 million tons of municipal waste is produced in daily life, over 20 times than that produced in 10 years ago. How to improve the management of municipal solid waste and resources recycling is the important policy of governments around the world.

Recycling and reclaiming of resources is an eco-efficient strategy, and a paragon of sustainable

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development. According to our survey of the literature, several multiple criteria decision making (MCDM) methods have been used to deal with environmental problems. The main approaches can be classified based on the type of decision model they used (Lahdelma et al., 2000):

(1) Value or utility function based methods, such as multiattribute utility theory (Keeney and Raiffa, 1976; Teng and Tzeng, 1994; Tzeng et al., 1996), AHP (Saaty, 1980), DEA (Oral et al., 1991), and the stochastic multiobjective acceptability analysis methods (Lahdelma et al., 1998).
(2) Outranking methods such as ELECTRE methods (Siskos and Hubert, 1983; Grassin, 1986; Roy and Bouyssou, 1986; Roy, 1991; Hokkanen and Salminen, 1997), PROMETHEE methods (Brans and Vincke,1985; Briggs and others, 1990), and GFD method (Caruso et al., 1993).

In this paper we focus on two multicriteria evaluating methods, data envelopment analysis (DEA) and grey relational analysis (GRA). The former originally developed by Charnes, Cooper and Rhodes in 1978, which method applied linear programming technique to measure the efficiency of decision making units (DMUs), since then there are considerable quantity of popular empirical use of linear programming techniques for calculating efficiency scores is due to the *DEA model* introduced to the general research public. The later first proposed by Deng in 1982, which method typically is based on the assumption that a system is uncertain and that the information regarding the system is insufficient to build a relational analysis or to construct a model in order to characterize the system.

The two mentioned popular evaluating techniques for multi-criteria decision-making problem, GRA and DEA, are briefly summarized in Section 2. Then in Section 3 an empirical case applying the MCDM methods from Section 2 for management and recycling of municipal solid waste in Taiwan is presented, after which we discuss and show how the MCDM methods in this paper are effective. Finally, conclusions are presented in Section 4.

2. Two Evaluation Methods for Performance of Environmental Management

Recently, environmental concerns have raised public awareness of environmental issues and are driving forces for regulation. The impact of regulation on the cost of production is expected to become an important determinant for the international competitiveness of industries. In response to cost pressures, industries have launched a number of initiatives aimed at improving efficiency and reducing environmental impact. Moreover, the management and development of reclaiming techniques for municipal solid waste and industrial waste not only the important index of government policy, but also the achieving goals for sustainable development of human being.

As mentioned above, several techniques for assessment of environmental issues, in this section we only summarize the grey relational analysis and data envelopment analysis methods in briefly.

2.1 Data Envelopment Analysis

Charnes, Cooper and Rhodes (1978) introduced a ratio definition of efficiency, which generalized the single-output to single-input classical engineering-science ratio definition to multiple outputs and inputs without requiring preassigned weights, where the weights are determined by the model. DEA model measures efficiency by estimating an empirical production function that represents the highest values of outputs that could be generated by relevant inputs, as obtained from observed input-output vectors for the analyzed DMUs. The inefficiency of a DMU is then measured by the distance from the point representing its input and values to the corresponding reference point on the production function.

There are a number of mathematical formulations of DEA all sharing the principle of envelopment. An output vector Y_k for DMU_k is enveloped from above when the model identifies a combination of other output vectors whose values are equal to or greater than all the elements in Y_k. Similarly, the input vector X_k is enveloped from below when the model finds a combination of other input vectors whose values are smaller than or equal to all the elements in X_k . If the pair $\left(X_k, Y_k\right)$ cannot be enveloped simultaneously by a combination of other DMUs, then DMU_k is efficient. In general, the set of efficient DMUs selected for evaluating an analyzed DMU defines one facet of the piecewise linear empirical production function. A linear combination of these DMUs serves as a reference point for the measurement of the inefficiency of DMU_k .

DEA makes no assumptions concerning the internal operations of a DMU. Rather, DEA treats each DMU as a "black box" by considering only the inputs consumed and outputs produced by each DMU. This perspective is often appropriate and sufficient. For example, if the purpose of the analysis is to identify inefficient DMUs and evaluate the extent of their inefficiency, then a "black box" approach is adequate. However, such an approach provides no insight regarding the locations of inefficiency and cannot provide process specific guidance to DMU managers to help them improve the DMU's efficiency. The general formulation of DEA (CCR model) can be expressed as follows:

$$
\begin{aligned}
Max \quad & h_0 = \sum_{j=1}^{s} u_j y_{j0} \\
s.t. \quad & \sum_{i=1}^{r} v_i x_{i0} = 1, \\
& \sum_{j=1}^{s} u_j y_{jk} - \sum_{i=1}^{r} v_i x_{ik} \le 0, \quad \forall k \\
& v_i, u_j \ge \varepsilon > 0, \quad \forall i, j
\end{aligned}
\tag{1}
$$

The objective here is to find the largest sum of weighted outputs of DMU_k while keeping the sum of its weighted inputs at unit value and forcing the ratio of the sum of weighted outputs to the sum of weighted inputs for any DMU to be less than one. The dual program solves for each DMU_k as:

$$
\begin{aligned}
Min \quad & h_k = \theta_k - \varepsilon \cdot \left(\sum_{i=1}^{r} \delta_i + \sum_{j=1}^{s} \sigma_j \right) \\
s.t. \quad & \sum_{k=1}^{m} x_{ik} \cdot \lambda_k + \delta_i = h_k \cdot x_{ik}, \quad \text{for } i = 1, \ldots, r \\
& \sum_{k=1}^{m} y_{jk} \cdot \lambda_k - \sigma_j = y_{jk}, \quad \text{for } j = 1, \ldots, s \\
& \delta_i \ge 0, \sigma_j \ge 0, \lambda_k \ge 0; i = 1, \ldots, r.\ j = 1, \ldots, s.\ k = 1, \ldots, m
\end{aligned}
\tag{2}
$$

The objective function of this model attempts to find a minimal value for an intensity factor θ_k that indicates the potential of a proportional reduction in all the inputs of DMU_k . In addition, the objective function seeks the largest slack values in all input-output dimensions. That is, it finds the reference point on the empirical production function which portrays DMU_k in the worst efficiency characterization.

2.2 Grey Relational Analysis

Since Deng proposed grey theory in 1982, related models have already been developed and applied to MCDM problems. Similar to fuzzy set theory, grey theory is a feasible mathematical means to deal with systems analysis characterized by poor information is lacking. Fields covered by grey theory include systems analysis, data processing, modeling, prediction, as well as decision-making and control (Deng, 1986; 1989; Tzeng and Tsaur, 1994).

The grey relational analysis is used to determine the relationship between two sequences of stochastic data in a grey system. The procedure may bear some similarity to the pattern recognition technology. One sequence of data is called the "reference pattern" or "reference sequence," and the correlation of the other sequence to the reference sequence is to be identified (Deng, 1986; Wu et al., 1996; Tzeng and Tsaur, 1994; Mon et al., 1995).

Let $\boldsymbol{x}_0$ be the reference pattern with n entries (i.e., dependent variable):

$$\boldsymbol{x}_0 = \left(x_0(1), x_0(2), \ldots, x_0(n)\right) \tag{3}$$

and $\boldsymbol{x}_t$ be one of the p patterns with n entries to be compared with $\boldsymbol{x}_0$ (each $\boldsymbol{x}_t$ has the same n number of entries as $\boldsymbol{x}_0$). The $\boldsymbol{x}_t$ is written as:

$$\boldsymbol{x}_t = \left(x_t(1), x_t(2), \ldots, x_t(n)\right) \qquad 1 \le t \le p \tag{4}$$

The set of the sequence $\boldsymbol{x}_t$ generally express the influencing factor of $\boldsymbol{x}_0$ ($\boldsymbol{x}_t$ be independent variable).

Definition 1. Let X be a factor set of grey relation, $x_0 \in X$ the referential sequence, and $x_i \in X$ the comparative sequence; with $x_0(k)$ and $x_i(k)$ representing respectively the numerals at point k for x_0 and x_i. If $\gamma(x_0(k), x_i(k))$ and $\gamma(x_0, x_i)$ are of real numbers, and satisfy the following four grey axioms, then call $\gamma(x_0(k), x_i(k))$ the grey relation coefficient and the grade of grey relation $\gamma(x_0, x_i)$ is the average value of $\gamma(x_0(k), x_i(k))$.

1. Norm Interval
   $0 < \gamma(x_0, x_i) \le 1, \forall k;\ \gamma(x_0, x_i) = 1 \quad iff \quad x_0 = x_i$
   $\gamma(x_0, x_i) = 0 \quad iff \quad x_0, x_i \in \phi$; where ϕ is an empty set.
2. Duality Symmetric
   $x, y \in X \quad \Rightarrow \quad \gamma(x, y) = \gamma(y, x) \quad iff \quad X = \{x, y\}$.
3. Wholeness
   $\gamma(x_i, x_j) \overset{often}{\neq} \gamma(x_j, x_i) \quad iff\ X = \{x_i \mid i = 0, 1, 2, \ldots, n\}, n > 2$.
4. Approachability
   $\gamma(x_0(k), x_i(k))$ decreasing along with $\left|(x_0(k), x_i(k))\right|$ increasing.

Deng also proposed a mathematical equation for the grey relation coefficient as following:

$$\gamma(x_0(k), x_i(k)) = \frac{\min_i \min_k \Delta_i(k) + \zeta \max_i \max_k \Delta_i(k)}{\Delta_i(k) + \zeta \max_i \max_k \Delta_i(k)} \tag{5}$$

where $\Delta_i(k) = \left|x_0(k) - x_i(k)\right|$, and ζ is the distinguished coefficient ($\zeta \in [0,1]$), we pick $\zeta = 0.5$ in general.

Definition 2. If $\gamma(x_0, x_i)$ satisfies the four grey relation axioms, then γ is called the grey relational map.

Definition 3. If Γ is the entirety of the grey relational map, $\gamma \in \Gamma$ satisfies the four axioms of grey relation, and X is the factor set of grey relation, then (X, Γ) will be calles as the grey relational space, while γ is the specific map for Γ.

Definition 4. Let (X, Γ) be the grey relational space, and if $\gamma(x_0, x_j), \gamma(x_0, x_p), \cdots, \gamma(x_0, x_q)$ satisfy $\gamma(x_0, x_j) > \gamma(x_0, x_p) > \cdots > \gamma(x_0, x_q)$, then we have the grey relational order as $x_j \succ x_p \succ \cdots \succ x_q$.

When the grey relational coefficient is conducted, we can then derive the grade of grey relation $\gamma\left(a_0, a_t\right)$ between reference alternative a_0 and each comparable alternative a_t defined as

$$\gamma\left(a_0, a_t\right) = \sum_{p=1}^{n} w_p \cdot \gamma\left(x_0(p), x_t(p)\right) \quad \forall t \tag{6}$$

where w_p denotes the normalized weight with respect to *p*-th criteria and such that $\sum_{p=1}^{n} w_p = 1$.

Finally, we can make the ranking of all alternatives based on which value of the grade of grey relation while following property hold:

$$a_i \succ a_j \quad iff \quad \gamma(a_0, a_i) > \gamma(a_0, a_j) \tag{7}$$

3. Empirical Study

Following the step of global sustainable development, management and recycling the municipal solid waste usually is the most important policy from government to each administrative division in Taiwan. In this study we select 23 administrative division in Taiwan be decision making units for evaluation. We employ Pearson correlation to decide the decision variables and verify these decision variables should meet the property of isotonicity among input and output variables.

TABLE 1. Raw Data of MSW for Evaluation

No.	DMU	x_1	x_2	x_3	x_4	y_1	y_2
1	Taipei County	5620	1680	6064374	64	1227320	58783
2	Ilan County	482	228	314335	5	156224	15618
3	Taoyuan County	1808	609	2056677	46	616658	38565
4	Hsinchu County	361	221	314209	13	146233	12923
5	Miaoli County	500	298	436092	13	182424	13546
6	Taichung County	1538	697	1314107	32	421145	47209
7	Changhua County	990	446	863866	28	373312	22029
8	Nantou County	742	229	408376	17	151495	11023
9	Yunlin County	731	304	483332	13	225512	15461
10	Chiayi County	515	223	411073	8	173658	11463
11	Tainan County	1081	431	874581	26	355339	25241
12	Kaohsiung County	1375	499	1426580	31	365562	28769
13	Pingtung County	912	416	660577	17	311355	13427
14	Taitung County	247	167	238621	3	92505	13823
15	Hualien County	381	230	190145	6	162131	12048
16	Penghu County	130	75	45594	9	32505	3559
17	Keelung City	527	186	248124	11	118517	23367
18	Hsinchu City	346	166	289674	17	134600	18624
19	Taichung City	1060	288	965888	45	198823	58709
20	Chiayi City	370	96	165172	21	105970	3439
21	Tainan City	942	276	867787	25	239630	33596
22	Taipei Municipality	5803	2361	5994732	51	994312	55082
23	Kaohsiung Municipality	2973	1217	3167107	44	473005	48030

To further understand the calculation procedures of the multiple criteria evaluation of data envelopment analysis and grey relation analysis. We applied these two approaches to evaluate the performance of municipal solid waste in Taiwan. The decision variables include four input variables and two output variables, the former composes of workforce (x_1, persons), equipment (x_2, number of vehicle), budget (x_3, TWN dollars) and recycling site (x_4, units), the later constitutes of total quantity of MSW (y_1, tons) and amount of recyclable collected (y_2, tons). Data is collected from web site of Environmental Protection Administration (EPA) which issued in 2001 in Taiwan (Table 1).

In order to evaluate the performance of municipal solid waste recycling across these administrative division, we first employ AHP to aggregate the subjective judgment of group decision-making behavior as weights evaluated by EPA authority member, the weights of evaluated variables lists as follows: ***w***=(0.180, 0.170, 0.180, 0.157, 0.173, 0.139).

TABLE 2. Grey Relation Coefficient Correspond To Evaluated Variables

No.	DMU	x_1	x_2	x_3	x_4	y_1	y_2	Grade of grey relation*	Rank
1	Taipei County	0.341	0.416	0.333	0.333	1.000	1.000	0.557	21
2	Ilan County	0.890	0.882	0.918	0.938	0.358	0.391	0.739	4
3	Taoyuan County	0.628	0.682	0.599	0.415	0.495	0.578	0.568	20
4	Hsinchu County	0.925	0.887	0.918	0.753	0.356	0.376	0.715	8
5	Miaoli County	0.885	0.837	0.885	0.753	0.364	0.380	0.695	10
6	Taichung County	0.668	0.648	0.703	0.513	0.426	0.705	0.610	18
7	Changhua County	0.767	0.755	0.786	0.550	0.412	0.430	0.626	17
8	Nantou County	0.823	0.881	0.892	0.685	0.357	0.367	0.679	13
9	Yunlin County	0.825	0.833	0.873	0.753	0.374	0.390	0.685	12
10	Chiayi County	0.880	0.885	0.892	0.859	0.362	0.369	0.719	6
11	Tainan County	0.749	0.763	0.784	0.570	0.407	0.452	0.629	16
12	Kaohsiung County	0.695	0.729	0.685	0.521	0.409	0.480	0.592	19
13	Pingtung County	0.784	0.770	0.830	0.685	0.395	0.379	0.651	15
14	Taitung County	0.960	0.926	0.940	1.000	0.345	0.381	0.770	1
15	Hualien County	0.919	0.881	0.954	0.910	0.359	0.372	0.744	3
16	Penghu County	1.000	1.000	1.000	0.836	0.333	0.334	0.766	2
17	Keelung City	0.877	0.911	0.937	0.792	0.350	0.439	0.728	5
18	Hsinchu City	0.929	0.926	0.925	0.685	0.353	0.408	0.717	7
19	Taichung City	0.753	0.843	0.766	0.421	0.367	0.997	0.686	11
20	Chiayi City	0.922	0.982	0.962	0.629	0.348	0.333	0.712	9
21	Tainan City	0.777	0.850	0.785	0.581	0.377	0.524	0.656	14
22	Taipei Municipality	0.333	0.333	0.336	0.389	0.719	0.882	0.486	23
23	Kaohsiung Municipality	0.499	0.500	0.491	0.427	0.442	0.720	0.507	22

* The grade of grey relation are computed by simple additive weighted method shown as Eqs.(6).

Table 2 lists the grey relation coefficient of these decision making units with respective to evaluated variables. Table 3 shows the relative efficiency score deriving by DEA model. We further look inside the preferred order (it means the relative performance of MSW implemented by these administrative division), according to the Wilcoxon signed ranks test, the test statistics indicated that ranking similarity of these two evaluated methods (DEA vs. GRA) is not significantly different (standardized t statistics = -1.725; asymptote significance = 0.085).

TABLE 3. Relative Efficiency Score Derived By DEA Model

No.	DMU	Score	Rank	V_{x_1}	V_{x_2}	V_{x_3}	V_{x_4}	U_{y_1}	U_{y_2}
1	Taipei County	0.9226	17	0.0000	0.0004	0.0000	0.0044	0.0000	0.0000
2	Ilan County	1.0000	1	0.0004	0.0030	0.0000	0.0171	0.0000	0.0000
3	Taoyuan County	1.0000	1	0.0001	0.0009	0.0000	0.0044	0.0000	0.0000
4	Hsinchu County	0.9715	13	0.0028	0.0000	0.0000	0.0000	0.0000	0.0000
5	Miaoli County	0.8620	18	0.0012	0.0014	0.0000	0.0000	0.0000	0.0000
6	Taichung County	0.8232	19	0.0001	0.0009	0.0000	0.0050	0.0000	0.0000
7	Changhua County	0.9986	12	0.0004	0.0011	0.0000	0.0001	0.0000	0.0000
8	Nantou County	0.7741	21	0.0000	0.0031	0.0000	0.0067	0.0000	0.0000
9	Yunlin County	0.9271	16	0.0000	0.0024	0.0000	0.0068	0.0000	0.0000
10	Chiayi County	1.0000	1	0.0000	0.0032	0.0000	0.0295	0.0000	0.0000
11	Tainan County	0.9584	14	0.0000	0.0016	0.0000	0.0036	0.0000	0.0000
12	Kaohsiung County	0.8110	20	0.0001	0.0012	0.0000	0.0072	0.0000	0.0000
13	Pingtung County	0.9393	15	0.0000	0.0018	0.0000	0.0050	0.0000	0.0000
14	Taitung County	1.0000	1	0.0033	0.0005	0.0000	0.0175	0.0000	0.0000
15	Hualien County	1.0000	1	0.0022	0.0003	0.0000	0.0115	0.0000	0.0000
16	Penghu County	1.0000	1	0.0000	0.0001	0.0000	0.0028	0.0000	0.0002
17	Keelung City	1.0000	1	0.0003	0.0008	0.0000	0.0300	0.0000	0.0000
18	Hsinchu City	1.0000	1	0.0028	0.0001	0.0000	0.0019	0.0000	0.0000
19	Taichung City	1.0000	1	0.0006	0.0000	0.0000	0.0004	0.0000	0.0000
20	Chiayi City	1.0000	1	0.0001	0.0090	0.0000	0.0051	0.0000	0.0000
21	Tainan City	1.0000	1	0.0001	0.0022	0.0000	0.0088	0.0000	0.0000
22	Taipei Municipality	0.6240	22	0.0000	0.0000	0.0000	0.0196	0.0000	0.0000
23	Kaohsiung Municipality	0.5250	23	0.0000	0.0007	0.0000	0.0045	0.0000	0.0000

In this study, we utilized two different models, AHP/GRA and DEA, to evaluate the performance of municipal solid waste recycling and treatment in Taiwan. The former method need to investigate the subjective preference information from participated evaluators firstly, and then integrate these criteria weights with grey relation model, which is one of the multiple criteria decision analysis methods. The latter method don't need to examine the preference structure of evaluated variables, input and output variables, it's a non-parameter method. These two evaluated methods may have different logical thinking; we deduced the similarity between them from statistic test as mentioned above.

4. Conclusions

In this study we employ two evaluation methods to cope with realm multiple criteria decision making problems. Through this research results, we successfully demonstrate these two methods are appropriate for real world evaluation issues. DEA models treat the DMU as a "black box." Inputs enter and outputs exit, with no consideration of the intervening steps. Consequently, it is difficult, if not impossible, to provide individual DMU managers with specific information regarding the locations of inefficiency within their DMUs. Furthermore, if there are some indicative qualitative variables but not including in traditional DEA model, it is situation of information insufficiency in evaluating process.

We further introduce how to use GRA to eliminate the uncertainty of information and then make the data more rational among the DMUs. Through empirical study we summarize some important conclusions as following:

1. Decision maker oftentimes have to reach their decision in grey processes thus the application of grey theory on the analysis of decision making is rather meaningful in practice.
2. The inclusion of the impact of weight preference from the decision making theory into the definition of grey relation grade can suitably reflect the preference structure of decision makers and render the processes of alternative evaluation of be more objective.
3. From the illustration of this example done in this paper it shows much of the easiness exploiting this method in application and the evaluation results are as well satisfactory.
4. Grey decision making refer not only to the explicit decision making of grey element but also focus on the association of grey relation and on the decision making conducted as of the ideas and methods of grey target. Therefore grey decision making based on grey theory should be give with wider spectrum of space for development and is worthy of further study.

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