Data envelopment analysis for evaluating Japanese Universities

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Abstract: In order to evaluate universities from various aspects, this study proposes method by utilizing DEA (Data Envelopment Analysis). The management of universities is complex and necessary to find out strength and weakness to be better educational institute. In this sense, DEA contributes for evaluation since it can show efficiency of universities based on multiple viewpoints. However, when the number of evaluated universities is increased, result of evaluation among universities is similar. Therefore, it is difficult to understand the specific points each university has. So this study proposes method for developed evaluation by ramifying DMU to some viewpoints. The utility and effectiveness of the proposed method are shown by numerical experiments.

Keywords: Data Envelopment Analysis, Linear Programming, Many-sided Evaluation, Decision Making Support.

I. INTRODUCTION

Recently the number of students who take entrance examination to university is decreasing due to declining birth rate in Japan. Moreover, public universities were reformed to be independent administrative organizations. Therefore, every university needs to consider the evaluation from the side of society in order to be attractive educational institute. In this sense, each university should evaluate themselves to understand the characteristics such as strength or weakness. Then better management policy can be prepared based on the valuable analysis. However, evaluation for universities is not often carried out. Even if there are evaluations, most of cases do not have the aspects from other universities [1]. That is why this study analyzes each university based on the characteristics by utilizing DEA (Data Envelopment Analysis).

DEA is a method for analyzing management efficiency of DMU (Decision Making Unit). The applicable field of DEA is now expanding such as policy evaluation, data mining, or so. The characteristics of DEA are as follows: (1) evaluate efficiency by multiple input and output data of DMU. (2) evaluate advantage aspects as much as possible by assigning variable weight to each elements of input and output. However, a lot of DMUs are evaluated as efficient if the number of input and output is large excessively compared with the number of evaluated DMUs. Thus analyst can not get informative knowledge from evaluation.

So this study proposes DEA method for many-sided evaluation to solve the above problem. Then the power of the proposed method is examined by applying data of Japanese universities.

II. DATA ENVELOPMENT ANALYSIS

1. Outline of DEA

DEA was proposed by A. Charnes et al. in 1978 as a method for management analysis. The applicable field of DEA is wide such as data mining or prospect of bankruptcy [2].

DEA regards each DMU as production function that produces output by input. Then the efficiency of DMU is calculated compared with other DMUs relatively. There are two characteristics DEA has; (1) weights are assigned to each input and output data and virtual input and output are generated. These weights are not fix but variable so that each DMU can employ suitable weight to be evaluated better. (2) common index for evaluation is shown as efficiency value. The efficient DMU gets efficiency value as one. On the other hand, inefficient DMU gets efficiency value less than one.

Assuming that there are *n* DMUs and each DMU is characterized by *m* input and *s* output. Then the DMU_K has input expressed as $x_{1k},\ldots,x_{mk}$ and output expressed as $y_{1k},\ldots,y_{sk}$. Here the efficiency value is shown by calculating following linear programming [2].

$$
\begin{aligned}
\max\ & \sum_{r=1}^{s} u_r y_{rk} \\
\text{s.t. } & \sum_{i=1}^{m} v_i x_{ik} = 1 \\
& -\sum_{i=1}^{m} v_i x_{ij} + \sum_{r=1}^{s} u_r y_{rj} \leq 0 \quad (j=1,\ldots,n) \\
& v_i \geq 0 \quad (i=1,\ldots,m) \\
& u_r \geq 0 \quad (r=1,\ldots,s)
\end{aligned}
\tag{1}
$$

Above formula signifies that weights are assigned to input of DMU_K to make it as one. Then DEA controls the efficiency value of other DMUs does not exceed over one based on the weights for DMU_K. Objective function has the role for maximizing output of remarkable DMU. Moreover, it is possible to analyze strong points of each DMU by weights. That is because input and output are considered in evaluation when the weights have value.

2. Mathematical problem

The problem is generated when the number of input and output elements are large compared with the number of DMUs. In DEA, the number of evaluation criteria is creased if the number of input & output elements is increased. Therefore, more DMUs are evaluated as the state of efficient than usual. Moreover, at least one advantage of input or output elements makes that DMU efficient. That is why the elements which do not have advantages are not emphasized so that more zero weights are assigned to more input and output. Thus excessive number of input and output lead the following two problems: (1) evaluation does not make sense because of many efficient DMUs. (2) many-sided evaluation can not be achieved due to many zero weights. To deal with these problems, there is a restriction for selecting input and output. Assuming that *m* input elements, *s* output elements and *n* DMUs, n should be satisfied with restriction of $n \geq \max\{m \times s, 3 \times (m+s)\}$. However, there are many cases that many-sided evaluation is carried out based on many input and output like evaluation for universities.

III. PROPOSED METHOD

This paper proposes the framework for many-sided evaluation without regard to the number of input, output and DMUs. This framework makes layered structure based on evaluation perspective and assigns input and output elements to each node that is perspective. Then input and output of upper layer include those of lower layer. It is possible to evaluate based on each perspective by calculating efficiency value of each node.

This chapter explains the proposition for making layered structure. Then the procedure of making layered structure is shown. Finally the example concerning comparison between DMUs is shown.

1. Hierarchization of DMU

There are *n* evaluated DMUs. And they have *m* input elements and *s* output elements. Here input elements are $X=(X_1,...,X_m)$ and expressed as $X_i=(x_{i1},...,x_{in})$. So X_i indicates i input group of all DMUs. Equally, $Y=(Y_1,...,Y_s)$, $Y_r=(y_{r1},...,y_{rn})$ are defined. The efficiency value of DMU_K shown as θ_K is calculated by (1) formula. Moreover, efficiency value is calculated based on possible production set S formed by input and output.

Next it is necessary to consider the case that specific input and output are utilized for analysis. New input and output groups are selected and they are denoted as $X'=\{X' \in X, X' \neq \phi\}$, $Y'=\{Y' \in Y, Y' \neq \phi\}$. Then the efficiency value of DMU_K shown as θ'_K based on this data set (X',Y') is calculated by (1) formula. It means this efficiency value is calculated based on possible production set S'. Thus $S' \in S$ is satisfied and two different efficiency values θ_K, θ'_K are followed inequality $\theta_K \geq \theta'_K$. The efficiency value of selected data is less than that of original data.

2. Relationship between nodes

The proposed method hierarchizes by resolving the evaluation perspective and assigns input and output elements to each node. In this time, input and output of upper layer have to include those of lower layer. Then analysis is carried out in each node. Thanks to the proposition in previous section, the efficiency value of lower layer never exceeds that of upper layer. Therefore, it is possible to treat the efficiency value of each node evenly since efficiency signifies the state of each DMU by unified way. Thus inefficient DMU as a whole never be the state of efficient in some node. And the reason for decline about efficiency is revealed. For example, which parts of node affect to the efficiency badly or how degree the specific DMU influences the efficiency. It is possible to analyze these kinds of knowledge from all perspective analyst prepares.

Moreover, comparison of the efficiency value among different nodes reveals the reason for the efficiency. For example, DMU in certain layer has efficiency value as one, and DMU in lower has also the same one. In this case, the node in lower layer strongly supports to upper node and its efficiency. On the contrary, if DMU in lower layer has efficiency value as 0.1, this node is factor to restrain the efficiency of upper node. Then new weight is developed to compare with linked nodes. Assuming that the DMU_K's efficiency value of β node in α layer is expressed as $\theta_K^{\alpha\_\beta}$ and the efficiency value of γ node in $\alpha+1$ layer is expressed as $\theta_K^{\alpha+1\_\beta}$. The new weight is calculated as follow:

$$w_\gamma^{\alpha,\alpha+1} = \frac{\theta_K^{\alpha+1\_\beta}}{\theta_K^{\alpha\_\gamma}} \quad (2)$$

The new weight is ration between layers and range is $0 < w^{\alpha,\alpha+1} \leq 1$. This weight signifies the importance of lower layer for supporting the efficiency of upper layer. In this sense, lower node is necessary factor for upper node to have higher efficiency if weight between them is one. On the contrary, lower node is weak perspective for upper one if the weight between them is few.

IV. NUMERICAL EXPERIMENTS

1. Data set and evaluation criteria

The experiments are carried out by using date of Japanese thirty-one universities. Then the proposed method constructs three layers and eight nodes. The practical figure of layered structure is shown in Fig.1.

As you can see in Fig.1., analyst is able to observe the evaluation from multiple aspects. Firstly, the efficiency is calculated based on each node. Next we would like to examine the evaluation of universities by gathering those kinds of experimental results.

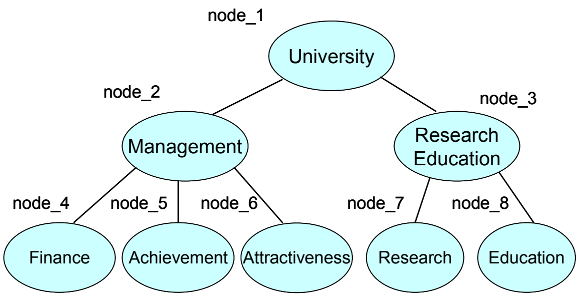

Fig.1. Layered structure

The experimental data consist of multiple elements and are divided to input data and output data as follows:
Input: 1. Number of faculty, 2. number of worker, 3. education and research expense, 4. Grant-in aid for management, 5. General and administrative expenses, 6. Profit of donation.
Output: 1. Maximum deviation, 2. Number of paper, 3. Number of graduate student, 4. Number of undergraduate student, 5. Number of books, 6. Grant-in-aid for scientific research, 7. Contract research funds, 8. Profit of business.

The general evaluation for universities is shown as node_1 in upper layer. It means that the efficiency value is the same as traditional DEA method and higher efficiency value is regarded as more efficient state. On the other hand, five nodes in lower layer are ramified functionally from general evaluation. Therefore, point of view concerning these five nodes is mentioned with showing input and output in each node. Here elements in each node are denoted by number shown in above paragraph.

<node_1> University
Input: 1～6　Output: 1～8
<node_2> Management
Input: 2, 4, 5, 6　Output: 1, 3, 4, 8
<node_3> Research and Education
Input: 1, 3　Output: 2, 3, 4, 6, 7
<node_4> Finance　Input: 4, 5, 6　Output: 8

The efficiency value in this node signifies how much university can get profit with possible funds that are input. To assume two types of high efficient DMUs is reasonable. (i) DMU which has larger profit than that of other DMUs. (ii) DMU which has smaller possible investment to the profit.

<node_5> Achievement　Input: 2, 4, 5, 6　Output: 1

The efficiency value in this node signifies how high university has deviation with possible funds and human resources. Thanks to this value, it is possible to examine how much DMUs invest funds to certain deviation. DMU which is higher efficiency operates by fewer funds. On the other hand, DMU which is lower efficiency invest funds excessively for their management.

<node_6> Attractiveness　Input: 2, 4, 5,6　Output: 3,4

The efficiency value in this node signifies how many university gather students with possible funds and human resources. DMU which is higher efficiency has high attractiveness. On the other hand, DMU which is lower efficiency has less attractiveness and need to improve the situation. For example, they can increase the number of students.

<node_7> Research
Input: 1, 3　Output: 3, 4

The efficiency value in this node signifies how many university get external funds or accomplishments of research. DMU which is higher efficiency does research admitted by outside.

<node_8> Education
Input: 1, 3　Output: 2, 6, 7

The efficiency value in this node signifies how much university invests funds and human resources to education for students. DMU which is higher efficiency operates by fewer resources. On the other hand, DMU which is lower efficiency operates by much funds and resources. Higher efficiency value is suitable for the side of university and lower efficiency value is favorable for the side of student.

2. Result

The experimental results are shown in Table 1. For instance, DMU_No. 2 has efficiency value as one based on "University" (node_1) and has it as 0.234 based on "Achievement" (node_5).

3. Discussion

(i) Comparison of the traditional and proposed method

The traditional method shows the efficiency value based on only "University" (node_1). In contract, the proposed method ramifies nodes so that there are eight nodes, namely eight efficiency value for one DMU.

Firstly, "University" (node_1) is remarkable. There are twenty-one DMUs which have efficiency value as one shown in Table. 1. Therefore, it is difficult to decide superiority or inferiority. This is one of the problems of DEA, or more specifically, relationship between the number of DMUs and that of input and output. Some of the same efficiency values exist when the number of input and output is large compared with that of DMUs.

The new seven nodes that the proposed method produces are notable. There are no DMUs which have efficiency value as one in all nodes. (the proposed method has characteristic as follow: the efficiency value of certain node never exceed that of upper node. Thus it is possible to restrain the number of DMU which has same efficiency value in all nodes in case of other data set.)

This result means that the proposed method can find some difference compared with the traditional method which is difficult to show superiority or inferiority regarding each DMU.

For example, the efficiency values of DMU_No.1 and DMU_No. 2 are one based on "University" (node_1) that is traditional way so that there is no difference. However, DMU_No. 1 is superior based on "Management" (node_2) and DMU_No. 2 is superior

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based on "Research and Education" (node_3). This is the difference of characteristic.

(ii) Analysis of strength or weakness for each university

Visualization concerning DMU_No. 28 is shown in Fig.1. in order to emphasize effectiveness of the proposed method. The name of node and efficiency value is shown on each node. The value shown in the link between nodes is weight. If this weight is less than one, lower node represents weakness compared with upper node. For example, the efficiency value based on "University" (node_1) is one. Then weight of "University"-"Management" is one and that of "University"-"Research and Education" is 0.648. Therefore, this DMU has room for improvement in the field of "Research and Education".

Then analysis about DMU_No. 28 is done by utilizing these weights. This DMU has high efficiency in the area of "Management" (left section in Fig.1.). Especially, "Achievement" gets higher value though the average in that node is . From these result, this DMU has strength regarding "Management", especially "Achievement" or "Attractiveness".

Then the efficiency value based on "Research and Education" (right section in Fig.1.) is less efficiency. Especially, "Research and Education" is lowest efficiency as 0.649. the weight of "Research and Education"-"Research" is also lowest value as and this is just bottleneck.

As a result, the proposed method is able to analyze which section is strength or weakness for each DMU by examining weights and efficiency values.

Table 1-(a). Efficiency value based on each node

DMU	Node				
	University (node_1)	Management (node_2)	Finance (node_4)	Achievement (node_5)	Attractiveness (node_6)
No. 1	1	1	0.494	0.234	1
No. 2	1	0.959	0.334	0.124	0.959
No. 3	1	0.950	0.413	0.183	0.950
No. 4	1	0.919	0.670	0.396	0.917
No. 5	1	0.900	0.393	0.230	0.900
No. 6	1	0.787	0.313	0.191	0.787
No. 7	0.958	0.776	0.316	0.159	0.776
No. 8	1	1	0.715	0.500	1
No. 9	1	0.940	0.467	0.314	0.940
No. 10	0.970	0.927	0.655	0.449	0.927
No. 11	1	1	0.473	0.275	1
No. 12	1	0.776	0.651	0.519	0.776
No. 13	1	0.959	0.674	0.240	0.959
No. 14	1	0.771	0.591	0.521	0.771
No. 15	0.802	0.672	0.603	0.607	0.671
No. 16	1	0.710	0.631	0.557	0.710
No. 17	1	1	0.977	0.953	1
No. 18	0.884	0.748	0.091	0.551	0.741
No. 19	0.876	0.658	0.617	0.658	0.612
No. 20	0.932	0.695	0.684	0.669	0.618
No. 21	0.945	0.609	0.583	0.602	0.598
No. 22	0.966	0.666	0.576	0.651	0.562
No. 23	1	1	1	1	1
No. 24	1	1	1	1	1
No. 25	1	1	0.964	0.813	1
No. 26	0.989	0.548	0.076	0.548	0.485
No. 27	0.982	0.805	0.666	0.805	0.662
No. 28	1	1	0.946	1	1
No. 29	1	0.721	0.438	0.496	0.721
No. 30	1	0.577	0.454	0.577	0.512
No. 31	1	0.679	0.489	0.679	0.515

Table 1-(b). Efficiency value based on each node

DMU	Node			
	University (node_1)	Research & Education (node_3)	Research (node_7)	Education (node_8)
No. 1	1	0.892	0.833	0.801
No. 2	1	1	1	0.996
No. 3	1	1	1	1
No. 4	1	1	1	0.955
No. 5	1	1	1	0.912
No. 6	1	1	0.967	1
No. 7	0.958	0.925	0.873	0.884
No. 8	1	1	1	1
No. 9	1	0.903	0.753	0.903
No. 10	0.970	0.900	0.658	0.886
No. 11	1	0.892	0.684	0.883
No. 12	1	1	0.914	1
No. 13	1	1	1	0.993
No. 14	1	1	0.904	1
No. 15	0.802	0.787	0.643	0.744
No. 16	1	0.967	0.899	0.917
No. 17	1	1	0.937	1
No. 18	0.884	0.820	0.735	0.766
No. 19	0.876	0.779	0.504	0.733
No. 20	0.932	0.802	0.448	0.779
No. 21	0.945	0.851	0.585	0.830
No. 22	0.966	0.838	0.805	0.674
No. 23	1	1	0.577	1
No. 24	1	1	0.550	1
No. 25	1	1	0.470	1
No. 26	0.989	0.875	0.618	0.850
No. 27	0.982	0.866	0.591	0.836
No. 28	1	0.649	0.446	0.632
No. 29	1	0.929	0.904	0.889
No. 30	1	0.924	0.865	0.759
No. 31	1	0.809	0.549	0.780

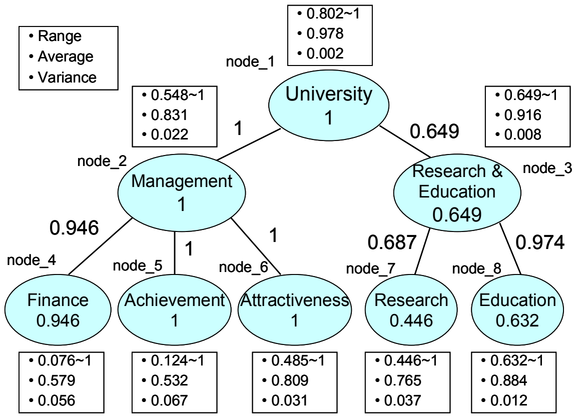

Fig.2. Visualization of DMU_No. 28

V. CONCLUSION

Though the traditional method sometimes can not find the superiority or inferiority, the proposed method solves such problem. It ramifies the DMU to multiple nodes that is viewpoint and shows the efficiency based on each node. Therefore, characteristics (strength or weakness) of each DMU can be revealed by efficiency value and weights between nodes. The proposed method works well for evaluation of universities and effectiveness is confirmed through the numerical experiments.

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