Efficiency Measurement and Ranking of Water Supply Service Malaysia by Using Hybrid DEA and PROMETHEE II Method

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Abstract. Water is a crucial resource in our daily life and is needed for rapid socio-economic development worldwide. Therefore, the evaluation of efficiency for water supply services is an important aspect to assure that the whole sector works efficiently. Data Envelopment Analysis (DEA) is a linear programming method to measure the efficiency of multiple decision-making units (DMUs) when the production process presents a structure of multiple inputs and outputs that can be applied for water service efficiency. However, the problem with the classical DEA method is that it lacks discrimination power where it fails to rank the efficient DMUs since all efficient DMUs obtained are with an efficiency score of one. Thus, this study integrates PROMETHEE II into classical DEA to rank the DMUs completely. This study aims to measure the efficiency and provide a complete ranking of water supply services for 14 states in Malaysia. Firstly, CCR output-oriented model is used to measure the efficiency score of the DMUs and then the PROMETHEE II method was applied to rank those efficient units. The findings proved that the proposed DEA-PROMETHEE II method can be successfully applied to give a complete ranking for all of the DMUs for the 14-water supply service in Malaysia.

Keywords: Water Supply Service · DEA · PROMETHEE II · Super Efficiency

1 Introduction

Water resources provide a wide range of services that are essential for long-term development which has been greatly driven by population expansion, modernization, and food and energy security which is due to its constant need [1]. Moreover, rapid human growth caused the fast expansion of several water supply networks within the last 50 years, and it is predicted to rise further [2]. The expansion of the water supply network has made a huge global concern in improving its efficiency to satisfy the demand for water supply around the world. When analyzing all types of productive activities, efficiency has

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been a major consideration, and study on the topic has resulted in a range of assessment approaches [3]. There are several mathematical measurements or quantitative approaches for measuring the relative efficiency of decision-making units (DMUs) where one of the mathematical approaches is Data Envelopment Analysis (DEA) which was introduced by [4] to measure the technical efficiency of the DMUs [5]. Much research addressing the management of water supply sectors has been conducted globally since 1986 with the application of DEA models [6]. DEA uses efficiency scores where the score that is equal to one will be considered as efficient DMUs. However, classical DEA models have several weaknesses which is a lack of discrimination power. Therefore, classical DEA fails to rank the efficient DMUs since all efficient DMUs obtained are with an efficiency score of one [7]. Thus, the complete ranking of DMUs could not be obtained.

PROMETHEE II is a superior strategy method for rating and selecting among a limited number of alternatives while taking into account a variety of competing criteria [8]. The application model of integrating the DEA and PROMETHEE II approach will generate the capability of DEA analysis to give a full-ranking result for the DMUs. Thus, in this study, the effectiveness of water supply services in 14 Malaysian states will be measured using the application of the DEA-PROMETHEE II model by considering inputs which are the total operating costs (OPEX) and the number of employees. Then, the outputs are water consumption and total income for the water supply service. There are three main objectives to be achieved in this study which are to measure the efficiency of water supply service in Malaysia by using the classical DEA method. Next, to contribute a full ranking of water supply service in Malaysia by integrating the DEA-PROMETHEE II method and lastly to compare the full ranking result with another DEA full ranking method which is the Super Efficiency method.

2 Methodology

2.1 Data Acquisition and the Determination of Input and Output

This study involves measuring the efficiency of 14 states of water supply service in Malaysia where the data on inputs and outputs was collected from the annual report of the Malaysian Water Industry Guide (MWIG) for the year 2017 as shown in Table 1. Three software were used in this research which are LINGO 19.0, Efficiency Measurement Software (EMS) and Microsoft EXCEL.

2.2 Data Envelopment Analysis (DEA) Method

CCR model was proposed by [4] which is a nonparametric mathematical linear programming technique that allows determining the best practices of the efficient frontier from efficient DMUs with multiple inputs and outputs. This model is also able to guide inefficient DMUs to become efficient. In this study, CCR Output-oriented model has been chosen to measure the efficiency score of the water service providers in Malaysia where the model is as follows:

$$\frac{1}{E^0} = \text{Minimize } h_j = \sum_{i=1}^{m} v_i X_{i0} \tag{1}$$

Table 1. Secondary Data of DMUs for 2017

State (DMUs)	Number of workers (Input 1)	Operational expenditure (OPEX) (Input 2)	Water consumption (MLD) (Output 1)	Total revenue (RM) (Output 2)
Johor	2220	587929	1320	1139807
Kedah	1418	296451	719	307299
Kelantan	816	101170	240	115153
F. T. Labuan	134	25608	48	33034
Melaka	805	156985	413	230956
Negeri Sembilan	1079	212455	519	275543
Pulau Pinang	1332	219923	826	336472
Pahang	1655	298411	582	175122
Perak	1075	227784	907	392244
Perlis	138	42480	89	33650
Sabah	1064	465119	582	335633
Sarawak	2399	194552	870	270875
Selangor	4569	2596082	3243	2094242
Terengganu	458	101333	427	134961

Such that,

$$\sum\nolimits_{r=1}^{s} u_r Y_{r0} = 1$$

$$\Sigma_{i=1}^{m} v_i X_{ij} - \Sigma_{r=1}^{s} u_r Y_{rj} \geq j = 1,\ \ldots, n$$

$$u_r, v_i \geq \varepsilon,\ \ r = 1, \ldots, s,\ \ i = 1, \ldots, m$$

where:

X_{ij} = Input
Y_{rj} = Output
h_j = The relative efficiency of DMU_j
v_i = Weight of input
u_r = Weight of output
ε = The small positive value
n = Number of states
s = Number of outputs
m = Number of inputs

2.3 Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE II)

Since DEA Method could not provide a full ranking for the efficient DMUs, the PROMETHEE II Method which is one of the multi-criteria decision-making methods will be used in this study to generate a complete ranking for water supply services in 14 states in Malaysia. The PROMETHEE method is a special type of MCDM tool that was initially developed by Brans in 1986. It is based on pairwise comparisons of all of the alternatives and was designed to handle quantitative and qualitative criteria with discrete alternatives. The PROMETHEE I method allows the partial ranking of the decision alternatives, whereas the PROMETHEE II method can provide the full ranking of the alternatives. This method highlights the importance of every criterion in creating each objective weight of the criterion. The weightage that will be used in step 5 is computed from Entropy Method before computing the full ranking. There are seven steps in PROMETHEE 11 as in [9]:

Step 1: Construct the decision matrix.

Step 2: Normalize the decision matrix by using Eqs. (2) and (3) for beneficial criteria and non-beneficial criteria, respectively.

$$Rij = \frac{\left[X_{ij} - minX_{ij}\right]}{\left[\max\left(X_{ij}\right) - \min\left(X_{ij}\right)\right]} \text{for i = 1, 2, 3, ..., m; j = 1, 2, 3, ..., n} \tag{2}$$

$$Rij = \frac{\left[\max(X_{ij}) - X_{ij}\right]}{\left[\max\left(X_{ij}\right) - \min\left(X_{ij}\right)\right]} \text{for i = 1, 2, 3, ..., m; j = 1, 2, 3, ..., n} \tag{3}$$

Step 3: Calculate the evaluative differences of i^{th} alternative with respect to another alternative, d_j (a,b) by using

$$d_j(a, b) = g_j(a) - g_j(b) \tag{4}$$

Step 4: Calculate the preference function, $P_j(a, b)$ using

$$P_j(a, b) = 0 \text{ if } R_{aj} \leq R_{bj} \text{ such that } \mathrm{D}(M_a - M_b) \leq 0$$

$$P_j(a, b) = R_{aj} - R_{bj} \text{ if } R_{aj} > R_{bj} \text{ such that } \mathrm{D}(M_a - M_b) > 0 \tag{5}$$

Step 5: Calculate the aggregated preference, $\pi(a, b)$ by using

$$\pi(a, b) = \frac{\sum_{j=1}^{n} w_j P_j(a, b)}{\sum_{j=1}^{n} w_j} \text{ where } \Sigma_{j=1}^{n} w_j = 1 \tag{6}$$

Given that $\sum_{j=1}^{n} w_j$ is the sum if the weight for the criteria.

Step 6: Determine the leaving and the entering outranking flow using Eq. (7) and (8) respectively.

$$\text{Leaving (positive)flow for } a^{th}\text{alternative, } \varphi^{+}(a) = \frac{1}{m-1}\sum_{b=1}^{m} \pi(a, b) \text{ where}(a \neq b) \tag{7}$$

$$\text{Entering (negative) flow for } a^{th} \text{ alternative, } \varphi^{-}(a) = \frac{1}{(m-1)} \sum_{(b=1)}^{m} \pi(a,b) \text{ where } (a \neq b) \tag{8}$$

Step 7: Calculate the net outranking flow for each alternative using

$$\varphi(a) = \varphi^{+}(a) - \varphi^{-}(a) \tag{9}$$

The ranking of all the considered alternatives depending on the values of $\varphi(a)$. The higher value of $\varphi(a)$, the better is the alternative. Thus, the best alternative is the one having the highest $\varphi(a)$ value. The result will be compared with another full-ranking method of the DEA Model which is the Super Efficiency Model which also provides a full ranking of the DMUs.

2.4 Super Efficiency DEA Model

The best performance of a DMU is reflected by an efficiency score of one in various DEA models where this efficiency score is often shared by multiple DMUs. Many methods have been presented under the label of super-efficiency methods to rank and compare efficient units [10]. Reference [11] explained that the basic idea of the Super efficiency model is to compare the unit under evaluation with a linear combination of all other units in the sample where the DMU itself is excluded. Thus, an efficiency score that exceeds unity is obtained for the unit because the maximum proportional increase in inputs preserves efficiency [12]. The advantage of the SE-DEA model is that it permits us to rank and provide a super-efficiency rating for efficient units [13]. Meanwhile, the efficiency score of the inefficient DMUs remains consistent with the CCR method. The model of Super Efficiency DEA as in [14] where θ is a scalar that designates the share of the j th DMU's input vector, which is required to produce the j th DMU's output vector within the reference technology and describe as follows:

Min θ.

Subject to:

$$\sum_{\substack{k=1 \\ k \neq j}}^{n} v_k \, X_k + s^- = \theta X_j$$

$$\sum_{\substack{k=1 \\ k \neq j}}^{n} v_k Y_k + s^- = Y_j$$

$$v_k \geq 0, \; k = 1, 2, \ldots, n$$

$$s^- \geq 0, \; s^+ \geq 0,$$

Where,

$k = 1, 2, 3\ldots,$ n are inputs
$k = 1, 2, 3\ldots,$ n are outputs
$j = 1, 2, 3\ldots,$ n are DMU's
v_k = intensity of the kth unit
X_j = m- dimensional input vector
Y_j = s- dimensional output vector

3 Result and Discussion

The result of the efficiency of water supply service in 14 states in Malaysia is discussed which involved two inputs (number of workers and OPEX) and two outputs (water consumption and total revenue) for the year 2017. CCR Output-oriented model attempts to maximize outputs without requiring more of any of the observed input values and PROMETHEE II is one of the MCDM techniques that complete the ranking of efficient DMUs. Both of these models are used in this study as the main mathematical model in finding the rank for the efficiency score of the water supply service provider. The result will be compared with another full-ranking method which is the Super Efficiency Method to validate the effectiveness of the DEA-PROMETHEE II method in providing a complete ranking for water supply service in Malaysia.

3.1 Efficiency Score and Ranking of DMUs

The results of the efficiency score and rank of the DMUs are shown in Table 2. The efficiency score for each DMU is determined by using Eq. (1) of the CCR Model while the rank of the DMUs is set by comparing the efficiency score of each DMUs that was obtained from the calculation. The efficiency score with the highest value will be at the top rank while the lowest efficiency score will be at the lowest rank. Since the CCR model is not a complete ranking model, 5 DMUs are having an equal efficiency score of 1which are Johor, Perak, Sarawak, Selangor and Terengganu. The states with efficiency scores of less than one are Kedah, Kelantan, F.T. Labuan, Melaka, Negeri Sembilan, Pulau Pinang, Perak, Perlis and Sabah with efficiency scores of more than 0.5 and Pahang having efficiency value of less than 0.5. Therefore, the hybrid DEA-PROMETHEE II approach was used to obtain the complete ranking of the efficient DMUs with Johor at the first rank followed by Perak, Terengganu, Sarawak and Selangor respectively. Then, the Super Efficiency method was used to validate the result from the DEA-PROMETHEE II method which then shows similar ranking results as can be seen in Table 2. Thus, this shows the capability and practicality of the application of the hybrid DEA-PROMETHEE II method in finding the complete ranking for the water supply service providers in Malaysia.

Table 2. Comparison of the ranking results between the Hybrid-DEA PROMETHEE II method and the Super Efficiency method

DMUs	CCR Model		PROMETHEE II		Super Efficiency Method	
	Efficiency Score	Rank	Efficiency Score	Rank	Efficiency Score (%)	Rank
Johor	1.0000	1	0.0833	1	135.55	1
Kedah	0.6073	13	-	13	60.73	13
Kelantan	0.6464	12	-	12	64.64	12

(*continued*)

Table 2. (*continued*)

DMUs	CCR Model		PROMETHEE II		Super Efficiency Method	
	Efficiency Score	Rank	Efficiency Score	Rank	Efficiency Score (%)	Rank
F. T Labuan	0.6868	11	-	11	68.68	11
Melaka	0.8110	7	-	7	81.10	7
Negeri Sembilan	0.7219	10	-	10	72.19	10
Pulau Pinang	0.9225	6	-	6	92.25	6
Pahang	0.4591	14	-	14	45.91	14
Perak	1.0000	1	0.0298	2	111.49	2
Perlis	0.7305	9	-	9	73.05	9
Sabah	0.7320	8	-	8	73.20	8
Sarawak	1.0000	1	-0.0497	4	106.12	4
Selangor	1.0000	1	-0.0564	5	101.57	5
Terengganu	1.0000	1	-0.0070	3	110.50	3

4 Conclusion

This study aims to measure the efficiency of the water supply service of 14 states in Malaysia for the year 2017. The first method used in this study is the DEA model. In this method, the CCR Output-oriented model is applied to measure the efficiency of the water supply service in Malaysia. However, the efficiency score that was obtained from the DEA-CCR model could not determine the most efficient water supply service in Malaysia as 5 states are having the same efficiency score of 1. Therefore, the hybrid of the DEA-PROMETHEE II method was used to fully rank the efficient DMUs. Evaluating the performance of water supply service is very necessary to determine the level of efficiency of water supply service operators in each state so that demand from consumers can always be met due to increasing population throughout the year, at the same time water supply operators can also improve the quality of their services. It is recommended for future researchers to compare the full ranking results with the SPAN performance indicators to determine the suitability of the DEA model that is discussed in this study as an alternative performance indicator for water supply services in Malaysia by using Spearman's rank correlation test. At the same time, hybrid models such as the fuzzy-DEA model or network process analysis (ANP)-DEA model can be applied for the next research.

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