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MODIFIED RUSSELL NETWORK MODEL FOR DETERMINING MALAYSIA WATER SUPPLY SERVICES PERFORMANCE

(Model Rangkaian Russell Terubah Suai untuk Menentukan Prestasi Perkhidmatan Bekalan Air Malaysia)

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ABSTRACT

A black-box analysis of Data Envelopment Analysis (DEA) has been widely used to measure water supply services performance. It is a single process, which does not take into account the internal structure of the operation. However, in the production of water supply services, rather than a black-box analysis, the operation can be expressed into a two-stage network process and therefore can be analysed using Network Data Envelopment Analysis (NDEA). Furthermore, the Network Russell (NR) model is one of many other models in NDEA. A modified NR model is introduced in this study, which incorporated an undesirable output factor and will be called Network Russell with Undesirable Output (NR-OU) model. The NR-OU model has been tested on data of water supply from 14 states in Malaysia and the results provide information about the stages or processes in the operation that needs more attention in order to improve the Malaysian water supply services performance.

Keywords: black-box analysis; network data envelopment analysis; network Russell with undesirable output; Malaysian water supply services

ABSTRAK

Analisis kotak hitam dalam Analisis Pengumpulan Data (DEA) telah digunakan secara meluas untuk mengukur prestasi perkhidmatan bekalan air. Ia merupakan proses tunggal (tidak berangkai) yang tidak mengambil kira struktur dalaman bagi sesuatu proses. Namun begitu, dalam pengeluaran bagi perkhidmatan bekalan air, operasi itu boleh dinyatakan sebagai proses rangkaian dua peringkat dan boleh dianalisis menggunakan Analisis Pengumpulan Data Rangkaian (NDEA). Selanjutnya, model Russell Rangkaian (NR) merupakan satu daripada model-model NDEA yang lain. Suatu model NR terubah suai telah diperkenalkan dalam kajian ini, yang menggabungkan faktor output tidak diingini dan digelar sebagai model Russell Rangkaian dengan output tidak diingini (NR-UO). Model NR-OU ini telah diuji ke atas data pembekalan air daripada 14 negeri di Malaysia dan keputusannya telah memberikan maklumat tentang peringkat-peringkat atau proses-proses di dalam operasi yang memerlukan lebih perhatian untuk menambah baik prestasi perkhidmatan bekalan air di Malaysia.

Kata kunci: analisis kotak hitam; analisis pengumpulan data rangkaian; Russell rangkaian dengan output tidak diingini; perkhidmatan bekalan air Malaysia

1. Introduction

Performance measurement is important to improve the efficiency of the water supply services. One of the techniques to measure the efficiency is by benchmarking. Benchmarking techniques in the water industry have been used by different institutions such as the International Water Association (IWA), World Bank Group (WBG), Office of Water Services, United Kingdom (OFWAT) and Association of Drinking Water Companies throughout Indonesia (PERPAMSI) to measure and improve their respective water sector performance. Among the most widely used benchmarking methods in the water services are partial indicators such as cubic meters of water per kilometre per day and many others that have been used as simple performance indicators (PI).

The performance measurement method that has become popular in the water industry is a technique based on production frontier approach known as Data Envelopment Analysis which is better known as the DEA technique pioneered by Charnes *et al*. (1978) involving multiple inputs and outputs in the measurement of a single integrated model.

According to Romano and Guerrini (2011), beginning with a study pioneered by Byrnes *et al*. (1986), hundreds other studies around the world on the performance of the water supply services sector have been using the DEA model since 1986. Lambert *et al*. (1993) is among the studies that used the DEA method to compare the efficiency of public and private water utility in America. Whereas, studies in developing countries such as Anwandter and Ozuna (2002) had also used DEA for the study of the water supply industry in Mexico. Garcia-Sanchez (2006) who also studied the efficiency of the water utility in Spain using DEA. Furthermore, there is a study on the efficiency of the water supply system governance in the Palestinian territories by Alsharif *et al*. (2008).

However, most of the aforementioned DEA analysis only focuses on the overall structure of operation process that ignores the internal structure or internal stage of water supply services operation. In reality, the internal structure or stage in the water supply system can be described as a two-stage process, namely water treatment in the first stage and water distribution process in the second stage.

Previous studies use conventional Data Envelopment Analysis (DEA) which assumes that units measured as black-box and internal structures or operations according to levels are ignored. For example, only inputs for sources before the water treatment process and the final output of the water distribution process are considered. Intermediate factors such as the amount of treated water produced before the distribution process is always disregarded. Therefore, the network structure model is more appropriate to describe the actual structure of the clean water supply system.

To take the internal structure or operating network of a process into consideration, Färe and Grosskopf (1996) became the first to propose the use of the network DEA (NDEA) model. The NDEA model application is when inputs and outputs are involved for measured units that form a network or stack structure, in contrast to a single structured conventional DEA (black-box). NDEA has become an important area in the development of models based on DEA (Cook *et al*. 2010).

Since the operation of water supply services can be described as a two-stage network structure, where the output of the water treatment process (stage 1) becomes the input to the water distribution process (stage 2), it is suitable to apply the two-stage NDEA model to measure the performance of water supply services as well as to study more in-depth findings that cannot be obtained through conventional DEA approaches. Since the performance measurement of water supply services using the NDEA model variation is either non-existent or just a few, the network model is applied in the Malaysian water supply service.

However, there is a major problem faced by water supply services, namely leakage crisis or water loss that is closely related to the quantity of Non-Revenue Water (NRW). This issue can lead to a decrease in output thereby bring losses specifically in the form of revenue to the management. This study emphasizes the NRW factor as this issue has become one of the important issues as it affects the credibility of water supply services not only in Malaysia but also worldwide.

Furthermore, the Malaysian government has spent substantial expenditure on the NRW reduction program. In Budget 2018, RM1.4 billion has been allocated for the NRW program. Therefore, performance measures involving NRW are important and need to be monitored.

The NRW level will be monitored by the authorities to serve as one of the performance indicators issued by SPAN (Ministry of Finance Malaysia 2017).

By considering the above reasons, there is a need to measure the performance of utility services or water operators in Malaysia by applying the NDEA model to represent the two-stage process of water supply operations and incorporating the undesirable output factor of the NRW for this study. The study hopes to provide the best way to develop new performance indicators (addition to SPAN's performance indicators) for water utility as well as to guide the management of a more quality water supply system.

2. Model Framework of Malaysia Water Supply Sector

The selection of variables is based on variables that have been used in previous researches (Thanassoulis 2000; Anwandter & Ozuna 2002; Garcia-Sanchez 2006; Picazo-Tadeo *et al.* 2008) and discussions with representatives from the water supply sector. Figure 1 illustrates the two-stage network structured water supply sector framework and the selected input-output variables.

The model of the water supply sector consists of two-stage process where each stage has different input-output variables. In the first stage, the water treatment process uses two input variables, namely operating expenditure (OPEX) and raw water to produce output i.e. treated water production. This treated water production will be used as input for the second stage which is also known as the intermediate variable. While in the second stage, another input is the pipeline length which produces two outputs of stage 2, namely total revenue (desirable output) and NRW (undesirable output).

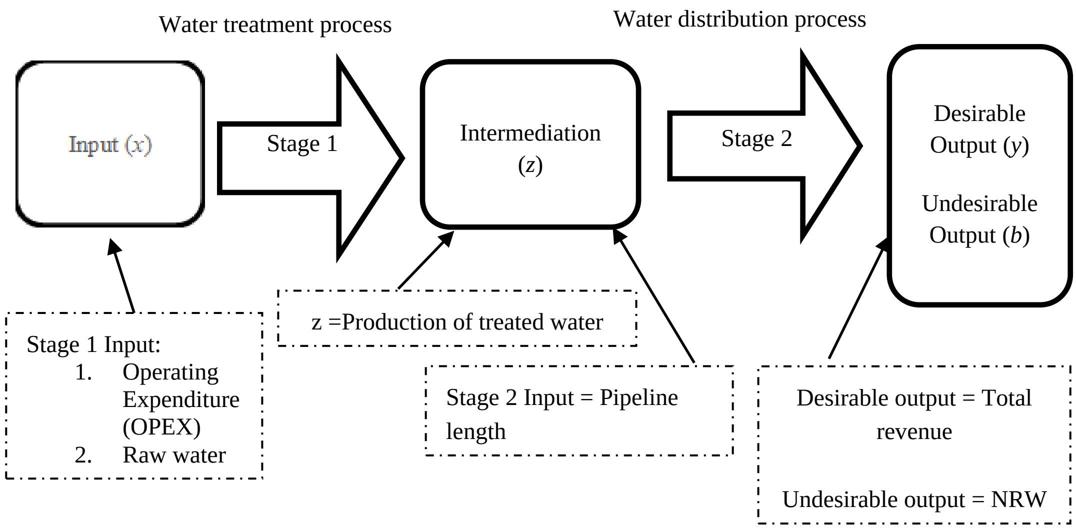

Figure 1: Selection of input-output variables of two stages of the water supply sector process

Operating expenditure (OPEX) consists of all the variables of resources used to distribute treated water from water plants to consumers. The lower is the OPEX value for a water utility, the more efficient is the water utility (Thanassoulis 2000). The unit to be used for OPEX is Ringgit Malaysia (RM). Raw Water refers to the amount of untreated raw water from the resources of water supply. Two types of raw water resources in Malaysia are Surface Water (which accounts for 97% of raw water resources such as rivers and dams) and Groundwater (such as wells, which contribute 2% to raw water supply resources) (SPAN 2016). The unit to be used for this raw water is Million Litres per Day (MLD) to represent the amount of Litre (million) of water per day.

The production of treated water is the amount of treated water produced by water treatment plants before the beginning of the water distribution process. The unit to be used for this raw water is MLD to represent the amount of Litre (million) of water per day. Pipeline length is closely related to the total number of connections that illustrates the number of connections of water supply for consumers that are distributed by the water utility while the pipeline length reflects the area of water dispersion capacity for the consumers. These two variables represent the scale size of the water supply distribution network (Thanassoulis 2000).

Total Revenue is the proceeds obtained including Tariff Revenue and Non-Tariff Revenue generated by bills issued to consumers who have reached and consumed the water (the reading of the consumers' main pipeline connection). NRW is the difference between the amount of water produced at the water treatment plant before being distributed with the amount of water billed at the consumers' premises meter. It can also be understood as clean water that has been distributed in the water distribution system and reaches customers but is not billed. NRW is clearly an undesirable output in the water distribution process.

After identifying the involved variables, the next step is to collect the data. Existing information from SPAN and MWA have been considered when choosing the selected variables. The important aspects that need to be emphasized when selecting variables are the availability of data for each variable for each selected Decision Making Unit (DMU).

Table 1: Data Set for 14 DMUs in year 2014

DMU	OPEX (RM)	Raw Water (MLD)	Water Production (MLD)	Pipeline Length (KM)	Outcome (RM)	NRW (MLD)
A	736,167	1,683	1,640	20,898	853,527	426
B	260,748	1,388	1,294	11,770	290,591	596
C	80,276	493	445	6,698	98,410	220
D	27,752	71	69	506	16,241	20
E	157,696	732	478	4,851	184,292	102
F	176,535	870	744	8,575	187,948	267
G	199,037	1,152	995	4,335	278,504	182
H	251,605	1,183	1,108	10,307	153,056	588
I	228,555	1,283	1,237	11,325	350,333	379
J	25,249	228	216	1,877	34,019	121
K	446,482	1,196	1,196	15,031	224,508	618
L	230,398	1,368	1,192	11,797	263,605	381
M	1,727,899	4,648	4,593	27,251	2,023,915	1,545
N	126,321	664	605	8,397	123,939	188

Since the objective of this study is to produce more comprehensive performance indicators compared to SPAN performance indicators, the data used are data for year 2014 as shown in Table 1.

As such, data is taken directly from reports published by MWA of which information is obtained from the Ministry of Energy, Green Technology and Water as well as SPAN. The report is a testimony to the success of the authorities in providing water sector services in the country. The reports were published annually and named as Malaysia Water Industry Guide or its abbreviation MWIG. MWIG has entered its 16th year of publication and is widely known as the main publication for the water industry in Malaysia which comprises of both water supply and sewerage services. MWIG is intended to facilitate stakeholders such as players in the water industry, government agencies, researchers, academics, financial institutions and others (MWA 2017).

3. Two Stages Performance Measurement Model with Undesirable Output of the Water Supply Sector

This section will discuss the development of the Russell Network with Undesirable Output (NR-UO) model. The new NR-UO model will be used to measure the performance of the water supply sector in Malaysia. From the establishment of the input-output, the NR-UO model (1) for the performance measurement of the two-stage water supply sector process is as follows:

$$Min\,\frac{w_1(\frac{1}{2}(\theta_1^1+\theta_2^1)+w_2(\theta_1^2)}{w_1(0)+w_2((\varphi_1^2)+(\gamma_1^2))}$$

Subject to:

$$\begin{aligned}
&\theta_1^1 x_{1o}^1 \geq \sum_{j=1}^{J} x_{1j}^1\lambda_j^1;\;\; \theta_2^1 x_{2o}^1 \geq \sum_{j=1}^{J} x_{2j}^1\lambda_j^1;\, \theta_1^2 x_{1o}^2 \geq \sum_{j=1}^{J} x_{1j}^2\lambda_j^2\\
&\varphi_1^2 y_{1o}^2 \leq \sum_{j=1}^{J} y_{1j}^2\lambda_j^2;\; {\gamma_1}^2 b_{1o}^2 = \sum_{j=1}^{J} b_{1j}^2\lambda_j^2\,;\\
&\sum_{j=1}^{J}\lambda_j^1 z_{1j}^{(1,2)} - \sum_{j=1}^{J}\lambda_j^2 z_{1j}^{(1,2)} \geq 0 \qquad (1)\\
&\sum_{j=1}^{J}\lambda_j^1 = 1\,, \sum_{j=1}^{J}\lambda_j^2 = 1\\
&\theta_1^1,\theta_2^1,\theta_1^2 \leq 1, \gamma_1^2 \leq 1, \varphi_1^2 \geq 1, \lambda_j^1,\lambda_j^2 \geq 0
\end{aligned}$$

Model (1) is a two-stage model where w_1 is the relative weight for stage 1 while w_2 is the relative weight for stage 2. Since both stages in the water supply sector process are equally important, then the weight for both w_1 and w_2 has equal value of 0.5. There are two inputs at stage 1 where θ_1^1 and θ_2^1 each represents the input variable respectively. Meanwhile θ_1^2 represents input variable for the one input at stage 2. Freshwater production is the result of stage 1 which is the intermediate product, $z_1^{(1,2)}$. Both desirable and undesirable outputs in stage 2 are represented by φ_1^2 and γ_1^2 respectively. x_{nj}^k is the input data value given by stage k with input n for each DMUj $(j \in \{1, \dots, J\})$. Similarly y_{mj}^k and b_{lj}^k are the data values for desirable output and undesirable output respectively according to stage k with desirable output m and undesirable output l for each DMUj. While λ_j^k is the variable representing the weight of each DMUj for respective stage.

To separately calculate the efficiency score for stage 1 (water treatment process) and stage 2 (Water distribution process), two models are introduced. Model (2) is designed for stage 1 while stage 2 uses Model (3). Stage 1 has two inputs with only one intermediate output. The numerator in the objective functions of stage 1 is the average value of efficiency for the two inputs at the stage. Meanwhile the denominator is denoted only by the average efficiency of the intermediate output since there is no desirable output or undesirable output at stage 1. The model (2) for stage 1 is as follows:

$$Min \ \frac{\frac{1}{2}(\theta_1^1 + \theta_2^1)}{(\bar{\varphi}_1^1)}$$

Subject to:

$$\begin{aligned} &\theta_1^1 x_{1o}^1 \geq \textstyle\sum_{j=1}^J x_{1j}^1 \lambda_j^1; \ \theta_2^1 x_{2o}^1 \geq \textstyle\sum_{j=1}^J x_{2j}^1 \lambda_j^1; \\ &\textstyle\sum_{j=1}^J \lambda_j^1 z_{1j}^{(1,2)} \geq \bar{\varphi}_1^1 z_{1o}^{(1,2)}; \textstyle\sum_{j=1}^J \lambda_j^1 z_{1j}^{(1,2)} - \textstyle\sum_{j=1}^J \lambda_j^2 z_{1j}^{(1,2)} \geq 0; \\ &\textstyle\sum_{j=1}^J \lambda_j^1 = 1; \\ &\theta_1^1, \theta_2^1 \leq 1, \bar{\varphi}_1^1 \geq 1, \lambda_j^1, \lambda_j^2 \geq 0. \end{aligned} \tag{2}$$

Based on Figure 1, there are one input and one intermediate input to produce one desirable output and one undesirable output in stage 2. Then the numerator in its objective function is the value of average efficiency for one input at stage 2 and one intermediate input. Meanwhile the denominator is the average efficiency for one desirable output and one undesirable output. Model (3) is therefore the efficiency model for stage 2:

$$Min \ \frac{\frac{1}{2}(\theta_1^2 + \bar{\theta}_1^2)}{\frac{1}{2}(\varphi_1^2 + \gamma_1^2)}$$

Subject to:

$$\begin{aligned} &\theta_1^2 x_{1o}^2 \geq \textstyle\sum_{j=1}^J x_{1j}^2 \lambda_j^2; \textstyle\sum_{j=1}^J \lambda_j^2 z_{1j}^{(1,2)} \leq \bar{\theta}_1^2 z_{1o}^{(1,2)}; \\ &\varphi_1^2 y_{1o}^2 \leq \textstyle\sum_{j=1}^J y_{1j}^2 \lambda_j^2; \ \gamma_1^2 b_{1o}^2 = \textstyle\sum_{j=1}^J b_{1j}^2 \lambda_j^2; \\ &\textstyle\sum_{j=1}^J \lambda_j^1 z_{1j}^{(1,2)} - \textstyle\sum_{j=1}^J \lambda_j^2 z_{1j}^{(1,2)} \geq 0; \ \textstyle\sum_{j=1}^J \lambda_j^2 = 1; \\ &\theta_1^2, \bar{\theta}_1^2, \gamma_1^2 \leq 1, \varphi_1^2 \geq 1, \lambda_j^1, \lambda_j^2 \geq 0. \end{aligned} \tag{3}$$

4. New Performance Indicator for Water Supply Sector

Water utility parties or operators in Malaysia are used as assessed DMU unit. New performance indicators for the water supply sector can be introduced as efficiency measure and effectiveness measure. It is concluded that the score value for stage 1 efficiency model (model 2) can represent the water treatment process (first stage process) which can determine the technical efficiency level of a water operator. Whereas the score value for stage 2 efficiency model (model 3) that represents the water distribution process (second stage process) can determine the level of service effectiveness of a water operator.

Furthermore, with this new measure, the stage or process of water supply operations that are relatively critical and needed extra attention can be identified as an effort to improve the performance of water operators in Malaysia. Therefore, new performance indicators from the NR-UO model are expected to provide better information and suitable to be used as an alternative or additional performance indicator.

4.1. *Performance of water supply operators using the NR-UO model*

The analysis result from this new proposal model showed the performance of 14 water supply operators in Malaysia as the operators of the water supply sector determined using the NR-UO model. Information on the performance of both stages of process can be determined separately. Subsequently, the process that requires more priority can be determined either it is the water treatment process or the water distribution process as a whole or separately for each water supply operator.

The results obtained after applying the NR-UO model to the data of water supply operators for year 2014 can be seen in Table 2. Score obtained for Overall score (column 2), Stage 1 (column 3) and Stage 2 (column 4) is computed by using model 1, model 2 and model 3 respectively. It is found that only two water supply operators are efficient as a whole, namely DMU D and M. DMU D and M are sets of DMUs that will be used as targets in improvements for inefficient DMUs. Additionally, it can be seen that the DMUs with overall efficiency status i.e. DMU D and M have an efficient status for both stages. Twelve DMUs have scores less than 1, so improvements have to be carried out for inefficient DMUs. Looking at the low average value of overall efficiency score (0.655), the majority of DMUs need to be improved.

Table 2: Performance of water supply operators using the NR-UO model for year 2014

Water supply operator	Overall score	Stage 1	Stage 2
A	0.896	0.792	1.000
B	0.604	0.970	0.625
C	0.520	0.913	0.557
D	1.000	1.000	1.000
E	0.703	0.586	0.875
F	0.513	0.814	0.585
G	0.951	0.863	1.000
H	0.409	0.889	0.439
I	0.632	1.000	0.633
J	0.583	1.000	0.583
K	0.422	1.000	0.501
L	0.512	0.928	0.536
M	1.000	1.000	1.000
N	0.423	0.881	0.463
Average	0.655	0.903	0.700

There is a situation where a DMU is efficient at stage 1, but inefficient at stage 2 and vice versa. For example, DMU A is inefficient at stage 1 but efficient at stage 2. This result shows that DMU A is efficient in the water distribution process (second stage process) but less efficient in the water treatment process (first stage process). The performance of DMU G is similar to DMU A except that the efficiency score for DMU G at stage 1 is higher than for DMU A.

On the other hand, the DMU I, J and K are performing efficiently at stage 1 but are inefficient at stage 2 in year 2014. The information about the efficiency of these two separate stages facilitates each DMU to determine which process is more critical and needs attention for improvement purposes. Meanwhile, six low-performing DMUs that are inefficient at both stages 1 and 2 are DMU B, C, E, F, H and L.

Looking at the average value of the efficiency score of stages 1 and 2, it is concluded that the average efficiency score in handling the process at stage 1 (0.903) is better than in handling the process at the stage 2 (0.700), hence if improvements are to be done, focus should be given to process in stage 2.

4.2. *Target projection of the new measurement model*

After the NR-UO programming model is applied to the data of water supply sector, the results of the measurement model will give the proportional values for the variables representing the inputs $\boldsymbol{\theta_1^1}$, $\boldsymbol{\theta_2^1}$ and $\boldsymbol{\theta_1^2}$ (two inputs at stage 1 and one input in stage 2). There is only one desirable output and one undesirable output where both are in the second stage. Therefore, $\boldsymbol{\varphi_1^2}$ and $\boldsymbol{\gamma_1^2}$ represent the variables of desirable output and undesirable output respectively.

The proportional value will be calculated for each inefficient DMU to find out what proportion should be used by the inefficient DMU for each variable from the original allocation to ensure that the DMUs achieve efficiency. A proportional value of 1 indicates that the variable has been used with 100% efficiency. No reduction should be made to the allocated values for the affected variable of inefficient DMUs. In other words, the DMU allocation is the best for the involved variable. If the proportional value is less than 1, there is a need to reduce the value of the involved variables to achieve efficiency. If the proportional value is greater than 1, there is a need to increase the value of the involved variable to achieve efficiency. The proportional value directly gives the percentage value that should be used instead of the original allocation of a DMU to achieve an efficient status.

For example, as shown in Table 3, see the proportional value of DMU A for year 2014, the proportional value of Input 1 (OPEX) is 0.58. While for Input 2 (Raw water), Input 1 in the second stage (Pipe length), Desirable Output 1 (Outcome) and Output 1 (NRW) have the proportional value of 1. As DMU A is an inefficient DMU as a whole, the proposed improvement is to use only 58% of the OPEX original allocation in the next year. Allocations used by other input-output variables can be maintained as the proportional value is 1, which means any addition or subtraction is not required.

Table 3: The proportional value of a target projection for year 2014

Water supply operator	Overall score	$\boldsymbol{\theta_1^1}$	$\boldsymbol{\theta_2^1}$	$\boldsymbol{\theta_1^2}$	$\boldsymbol{\varphi_1^2}$	$\boldsymbol{\gamma_1^2}$
A	0.896	0.584	1.000	1.000	1.000	1.000
B	0.604	0.877	0.924	0.630	1.840	0.694
C	0.520	0.409	0.542	0.239	1.000	0.375
D	1.000	1.000	1.000	1.000	1.000	1.000
E	0.703	0.374	0.550	0.944	1.000	1.000
F	0.513	0.804	0.958	0.564	1.817	1.000
G	0.951	0.906	0.897	1.000	1.000	1.000
H	0.409	0.832	1.000	0.664	3.212	0.648
I	0.632	0.910	0.917	0.601	1.395	1.000
J	0.583	1.000	1.000	0.733	2.395	0.575
K	0.422	0.474	1.000	0.460	2.215	0.624
L	0.512	0.908	0.865	0.580	1.865	1.000
M	1.000	1.000	1.000	1.000	1.000	1.000
N	0.423	0.754	0.890	0.411	1.916	1.000

For DMU J in year 2014 (see Table 3) which is inefficient as a whole, projection should be made for Input 1 in the second stage that is the pipe length should be reduced to only 73.3% of the actual length. The proportional value of the desirable output i.e. the Revenue is 2.395. This means the Revenue for DMU J should be increased by 2,395 times the actual Revenue value. The proportional value of the undesirable output is 0.575. Then the quantity of water loss i.e. the NRW needs to be reduced up to 57.5% of the actual NRW value for year 2014. This proposed target projection should be done for DMU J to achieve an efficient status.

It is known that NRW is a global issue in the handling of the water supply sector as low NRW level indicates the level of efficiency of the water utility's operations. The water utility parties strive to ensure that NRW levels are lowered to achieve efficient status. In this new measurement model, NRW element is also taken into account in calculating the overall efficiency of water utility or water supply sector operator/provider. The target projection for NRW is also available for each DMU unit. The seventh column of Table 3 shows the proportional value of the target projection for NRW level reduction for year 2014. Each water supply operator in Malaysia has different reduction target for NRW level and no longer only consider one target level to serve as a benchmark. This is different from the conventional method that set a single benchmark as the best practice and made into a target for all inefficient water operators.

5. Conclusions

The study has outlined a new model of the two-stage network measurement model in the water supply sector. This new model takes into account the internal structure factors that can be attributed to a two-stage network form. This is because the operation of the water supply system can be broken down into two major or interconnected processes, namely, the water treatment process from raw water in the first stage and the clean water distribution process to consumers in the second stage. This network structured measurement model also incorporates the undesirable output element into it. For the water sector industry, NRW is regarded as an undesirable output because NRW needs to be reduced even when it comes together with the desirable output i.e. the amount of water revenue that has been billed. To date, there is no two-stage network model framework with undesirable output in measuring the performance of the water supply sector as existing studies focus only on single-stage analysis (black-box). Thus, the two-stage model with undesirable output for measuring the performance of the water sector can be classified as an empirical contribution to the water supply services sector.

The new performance indicators introduced provide information from other perspectives as compared to existing SPAN performance indicators. New performance indicators can also enable improvement through detailed information of target projection for each variable for each operator's state. A more critical setting for process stages for each operator's state can also be known. Hence, these findings can have implications for the water supply and water sector policy and management in Malaysia.

Another advantage of the NR-UO model is the DMU unit performance measurements for each level can be viewed individually. The NR-UO model for measuring the performance of the water supply sector has two stages of process namely the water treatment process (stage 1) and the water distribution process (stage 2). The findings of this empirical analysis show that roughly, water operators in Malaysia are more efficient in managing the water treatment process than the water distribution process. However, each operator can individually determine which stage of the process is more critical for each state. This is by examining the efficiency score for level 1 and 2 respectively. Lower efficiency score indicates the stage of the process needs to be given more attention as a step towards improvement.

The efficiency measure of stage 1 of the NR-UO model can provide information on the efficiency of the water treatment process for each operator's state. This is an additional performance indicator because the stage of this process is not particularly touched in the existing SPAN performance indicators. The stage 1 efficiency model should be a performance indicator for technical efficiency that can also be interpreted as a measure of operational efficiency as at stage 1, the water treatment process is more to illustrate operations on behalf of the water supply operator.

Another advantage of the performance measurement model using the NR-UO model compared to the SPAN performance indicators is there is a target projection for each inefficient DMU. This information on target projection can be used as a benchmark for inefficient states individually for improvement to achieve efficient status. Each state has a separate benchmark for each involved variable. In contrast to the current practice in the water supply sector in the country which makes the operator's state with the highest performance rank as a single benchmark (best practice) for all inefficient DMU units.

The global issue of water leaks or NRW is also considered as an important factor for this study. The current policy applied in Malaysia is to set a single NRW percentage target as a standard benchmark or target level. For example, the national authority targets the NRW percentage average of only 15% for all states in Malaysia by year 2020. However, by the information of target projection from this NR-UO measure model, the target NRW level for each state is different and the efficiency will be achieved if the NRW level can be reduced as projected by the size model. The target projection information for NRW is the answer to one of the objectives of this study, which is to determine the NRW level that can be potentially lowered for each inefficient water supply operator in Malaysia.

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