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Measurement of DEA-Based ICT Development Efficiency Level with Modified CCR Method

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ABSTRACT

Data Envelopment Analysis (DEA) is the use of non-parametric mathematical programming that is useful for measuring the efficiency of the Decision Making Unit (DMU) of an organization. This study uses the Cooper and Rhodes (CCR) method known as the DEA-CCR multiplier which aims to determine the weight value of each input and output variable of the DMU being evaluated, but it is not sufficient to measure efficiency optimization. To get an efficient value of the weight value of each DMU as a reference to get updated DMU input and output values. So that the DMU efficiency value is obtained which is evaluated. The results of this study show how to modify the Multiplier Model-CCR into the Envelopment Model-CCR. Then displays the efficient level DMU which is evaluated as a result of the weight each DMU gets from the results of processing the LINDO application. Illustrations of changes in input variables and output variables are displayed in the form of tables and figures before and after the changes. The modified DEA-CCR model can also complete DMU super efficiency, effectiveness and productivity.

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A. INTRODUCTION

A Data Envelopment Analysis (DEA) is a relatively new "data-oriented" approach to evaluating the performance of a collection of entities called a Decision-Making Unit (DMU) that converts many inputs to many outputs (Thomas, 2019). The definition of a DMU is general and flexible. In recent years there have been various applications of DEA used to evaluate the performance of different types of entities engaged in many different activities in different contexts in different countries (Rouyendegh et al., 2020).

This DEA application can be used in various forms of DMU to evaluate the performance of entities such as hospitals, airlines, universities, cities, courts, business companies, and others, including the performance of the State, Province, and so on (Zhu, 2019). Because DEA applications require fewer assumptions, DEA has opened up possibilities for use in cases that have been resistant to other approaches due to the complexity of the relationship between the many inputs and the many outputs involved in the DMU (Zhu, 2020).

In the book, (Yang et al., 2022) DEA can be defined as a mathematical programming technique to measure the relative technical efficiency for each DMU, which is the maximum ratio between the weighted output and the weighted input. Geometrically the results of measuring the level of relative technical efficiency from the use of available resources (inputs) to produce several products or services (outputs) can be seen clearly in positions that are on the frontier line or not. In this case, the boundary is an efficiency benchmark (Ben Mabrouk et al., 2022) (Borozan, 2021). If the measurement results are on the boundary line then it is said to be efficient and if it is not at the boundary it is said to be inefficient.

Based on the basic concept of the CCR model discovered by Charnes, Cooper, and Rhodes, known as the DEA-CCR, the unit that shows the best performance is an efficiency score of one (Othman et al., 2016). This indicates that the score is part of the production boundary that cannot be compared with the boundary area (Cohn and Gotts, 2020).

As shown by (Sreedevi, 2016) (Kumari, 2019), explaining the efficiency of 10 private banks in Hyderabad using the DEA-CCR model approach. Explain that the most important sector in finance in the banking sector and the goal is to achieve greater output with lower inputs, or use the available inputs to the fullest (Grmanová and Ivanová, 2018) (Mada et al., 2022). Applying the DEA approach with a lot of input and output variables has clear benefits over using other simple performance approaches (Kohl et al., 2019). The results of the study studied on DEA suggest a reconsideration of efficiency that is carried out before and after merger activities are carried out in banks (Grmanová and Ivanová, 2018).

Formally, DEA is a methodology that leads to frontiers rather than central tendencies. instead try to fit the regression plane through the data center as in statistical regression, for example, one piecewise linear 'float' for a pause above the observations (Habibi, 2019) (Tanna et al., 2017). Because of this perspective, DEA has proven a knack for revealing relationships that have remained hidden from other methodologies. For example, consider what you mean by "efficiency," or more generally, what you mean by saying that one DMU is more efficient than the other (Gallardo-Gallardo, 2018).

Due to the conformity of efficiency in DEA with the following definition, which has the advantage of avoiding the need to assign measures of relative a priori importance to each input or output.

Definition 1 ***(Efficiency Expanded Pareto-Koopmans definition)****: A DMU is achieved at full efficiency (100%) if and only if no input or output can be increased without exacerbating some other input or output. In management and social science applications at a theoretical level, the most likely efficiency will not be known (Ewertowska et al., 2016).*

The previous definition is therefore replaced by emphasizing its use only with the empirical information available in the following definitions:

Definition 2 ***(Relative Efficiency)****: A DMU can be considered fully (100%) efficient based on the available evidence if and only if the performance of other DMUs does not indicate that some inputs or outputs can be improved without deteriorating some other inputs or outputs.*

Note that this definition avoids the need to examine prices or other weighted assumptions that should reflect the relative importance of different inputs or outputs (Bastos et al., 2018). It also avoids the need to specify explicitly the formal relationship that should exist between inputs and outputs. This basic type of efficiency referred to as technical efficiency in economics can be extended to other types of efficiency when data such as prices, unit costs, etc., are available for use in the DEA.

B. LITERATURE REVIEW

In the possible application to various activities, we use the term Decision Making Unit (DMU) to refer to any entity to be evaluated in terms of its ability to convert inputs into outputs. Such evaluations may involve government agencies and non-profit organizations as well as business enterprises. Evaluations may also be directed to educational institutions and hospitals as well as the police (or subdivisions thereof) or military units for which comparative evaluations of their performance should be made (Sreedevi, 2016).

DEA was introduced by (Curtis et al., 2020). The Data Envelopment Analysis (DEA) method was created as a tool for evaluating the performance of an activity within an entity unit (organization). The working principle of the DEA model is to compare input and output data from a data organization (DMU) with other input and output data in similar DMUs (Tavassoli et al., 2020) (Mohmmad Nejad and Ghaffari-Hadigheh, 2018). This comparison is done to get an efficiency value. Assume that there are n DMUs to evaluate, each DMU with m inputs and s outputs. For writing, x_{ij} $(i = 1, \ldots, m)$ and y_{rj} $(r = 1, \ldots, s)$ are used as input values and output values for DMU_j $(j = 1, \ldots, n)$, whose values are known and positive. According to the efficiency implications, the efficiency of DMU_j can be defined as

$$\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{1}$$

Where u_r and v_i are the output and input weights of the r-th output and i-th input.

The DMU efficiency measure can be calculated by solving the following mathematical programming problems:

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$$\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \tag{2}$$

$$\begin{aligned} s.t. \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{i0}} \leq 1, \quad j = 1, \ldots, n \\ u_r, v_j \geq r, \quad r = 1, \ldots, s; \quad i = 1, \ldots, m \end{aligned} \tag{3}$$

Where subscript zero represents the evaluated DMU, where x_{ij} is the observed input with type i of the j-th DMU and $x_{ij} > 0$ for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$. Likewise y_{rj} is the observed output value with type i of the j-th DMU and $y_{rj} > 0$ for $i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n$. While u_r and v_i are decision variables which are weighted values to determine the programming problems above. However, this problem has an infinite solution because if (u^* and v^*) are optimal, then for each $\alpha > 0$, (αu^* and αv^*) are also optimal. By following the Charnes-Cooper transformation, the solution we can choose is a representative (u, v) solution with the condition:

$$\sum_{i=1}^{m} v_i x_{i0} = 1 \tag{4}$$

So that a linear programming model is obtained which is equivalent to the fractional programming problem. The divisor in the efficiency measure above is made equal to one and the transformed linear problem can be written as:

$$\begin{aligned} \max z_0 = \sum_{r=1}^{s} u_r y_{r0} \\ s.t. \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{rij} \leq 0, \quad j = 1, 2, \ldots, n \\ \sum_{i=1}^{m} v_i x_{i0} = 1 \\ u_r, v_i \geq 0, \quad r = 1, 2, \ldots, s; \quad i = 1, 2, \ldots, m \end{aligned} \tag{5}$$

The linear programming problem above is often called the CCR model (Multiplier Model) with input-output orientation. The maximization is done by selecting the virtual multiple (ie weighted values) u and v which produces the greatest rate of virtual output per virtual input.

The problems mentioned above the weight of each variable can be obtained automatically. However, it cannot show the level of efficiency for DMUs that are not efficient so the solution is not optimal. For the optimal solution, it is necessary to modify the DEA-CCR model mentioned above with the DEA-CCR Model which is called the envelopment.

C. RESEARCH METHOD

As for changing the DEA-CCR model (Multiplier) into a modified DEA-CCR model (Envelopment), the reading pattern of the model is shown in the following table.

Table 1. Modification of CCR Method

No. DMU	Name DMU	Input			Output	Model DEA-CCR (Multiplier)
		x_1	x_2	x_3	y_1	
1	Aceh	$x_{1,1}$	$x_{2,1}$	$x_{3,1}$	$y_{1,1}$	$\max h_0 \sum_{r=1}^{s} u_r y_{r0}$
2	North Sumatera	$x_{1,2}$	$x_{2,2}$	$x_{3,2}$	$y_{1,2}$	
3	West Sumatera	$x_{1,3}$	$x_{2,3}$	$x_{3,3}$	$y_{1,3}$	$s.t. \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \ \ j = 1, \ldots, 33$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	
31	North Maluku	$x_{1,31}$	$x_{2,31}$	$x_{3,31}$	$y_{1,31}$	$\sum_{i=1}^{m} v_i x_{i0} = 1$
32	Papua	$x_{1,32}$	$x_{2,32}$	$x_{3,32}$	$y_{1,32}$	
33	West Papua	$x_{1,33}$	$x_{2,33}$	$x_{3,33}$	$y_{1,33}$	$u_r, v_i \geq 0, \ \ r = 1, \ldots, 3; \ \ i = 1$
		$\sum_{i=1}^{33} \lambda_j x_{1j}$	$\sum_{i=1}^{33} \lambda_j x_{2j}$	$\sum_{i=1}^{33} \lambda_j x_{3j}$	$\sum_{i=1}^{33} \lambda_j y_{1j}$	
Model DEA-CCR (Envelopment)		$\theta_0^* = \min \theta_0$ $s.t. \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, \ \ r = 1$ $\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_0 x_{i0}, \ \ i = 1, \ldots, 3$ $\lambda_j \geq 0, j = 1, 2, \ldots, 33$				Efficiency

From the DEA-CCR model (multiplier model) in equation (3), it can be modified by looking for the dual, by changing the calculation pattern by reading data from row to column to column to a row, which is known as the Envelopment Model or the modified DEA-CCR model. The model with this problem can be written for each DMU_0 as:

$$\begin{aligned} & \theta_0^* = \min \theta_0 \\ & s.t. \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, \quad r = 1 \\ & \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_0 x_{i0}, \quad i = 1, \ldots, 3 \\ & \lambda_j \geq 0, j = 1, 2, \ldots, 33 \end{aligned} \tag{6}$$

The linear programming problem above obtains the optimal solution θ_0^*, which is the efficiency value, also called the technical efficiency value or CCR efficiency for a certain DMU_0 (Envelopment model). If any set of positive weights makes $\theta_0^* = 1$, then the DMU is relatively efficient. This efficiency value is also known as the technical efficiency value or CCR efficiency. To get the overall efficiency value of DMU can be obtained by repeating the above process for each $DMU_j, j = 1, 2, \ldots, n$. The value is always less than or equal to one. For a relatively efficient DMU, it will be seen where the virtual input-output combination lies on the efficient frontier.

D. RESULTS AND DISCUSSION

View the value of the efficiency of each DMU from the dataset of ICT development and development in Indonesia, which can be seen in table 2 below.

Table 2. DMU Efficiency Value of each Province evaluated

No. DMU	Name DMU	Input			Output	Value Efficiency	Categories
		x_1	x_2	x_3	y_1		
1	Aceh	2.61	2.61	2.52	4.12	100%	Efficient
2	North Sumatera	2.53	2.74	2.59	3.28	79%	Not efficient
3	West Sumatera	1.89	2.48	2.41	2.76	82%	Not efficient
4	Riau	1.83	1.94	2.39	2.47	77%	Not efficient
5	Jambi	1.63	1.41	1.71	1.80	74%	Not efficient
6	South Sumatera	1.69	2.05	2.13	2.64	88%	Not efficient
7	Bengkulu	2.24	2.62	2.46	3.08	80%	Not efficient

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8	Lampung	1.78	1.82	1.90	2.52	84%	Not efficient
9	Bangka Belitung Island	1.98	2.13	2.25	2.84	83%	Not efficient
10	Riau Island	1.69	2.06	2.14	2.52	84%	Not efficient
11	DKI Jakarta	2.40	2.14	2.53	2.61	71%	Not efficient
12	West Java	3.35	3.55	3.30	3.56	63%	Not efficient
13	Middle Java	3.30	3.49	3.47	3.80	69%	Not efficient
14	Banten	1.81	2.37	2.35	2.40	74%	Not efficient
15	East Java	3.00	3.19	3.22	3.48	69%	Not efficient
16	DI Yogyakarta	2.91	3.13	3.24	3.60	72%	Not efficient
17	Bali	2.30	2.79	2.55	2.76	70%	Not efficient
18	West Nusa T.	2.04	2.44	2.41	2.36	66%	Not efficient
19	East Nusa T.	1.58	1.41	1.84	1.88	78%	Not efficient
20	West Kalimantan	1.78	1.93	2.03	2.64	86%	Not efficient
21	Middle Kalimantan	1.55	2.08	1.94	2.04	74%	Not efficient
22	South Kalimantan	2.78	2.61	2.34	2.55	67%	Not efficient
23	East Kalimantan	2.32	2.54	3.06	4.16	100%	Efficient
24	North Sulawesi	1.76	2.09	2.14	2.48	80%	Not efficient
25	Middle Sulawesi	1.95	1.87	1.97	2.80	90%	Not efficient
26	South Sulawesi	1.75	2.46	2.36	2.12	68%	Not efficient
27	Sulawesi Tenggara	1.80	1.94	2.23	2.64	83%	Not efficient
28	Gorontalo	1.78	1.70	1.89	2.92	100%	Efficient
29	West Sulawesi	1.68	1.76	1.95	2.60	89%	Not efficient
30	Maluku	1.90	1.93	2.12	3.28	100%	Efficient
31	North Maluku	1.30	1.41	1.49	1.88	83%	Not efficient
32	Papua	1.94	2.02	2.37	2.24	66%	Not efficient
33	West Papua	1.56	1.90	2.05	2.28	82%	Not efficient

In this case, data is entered into a model using the lindo application, which is seen in the example of the North Sumatra Province DMU. The program and results for the North Sumatra province DMU efficiency value are as shown in the following interface:

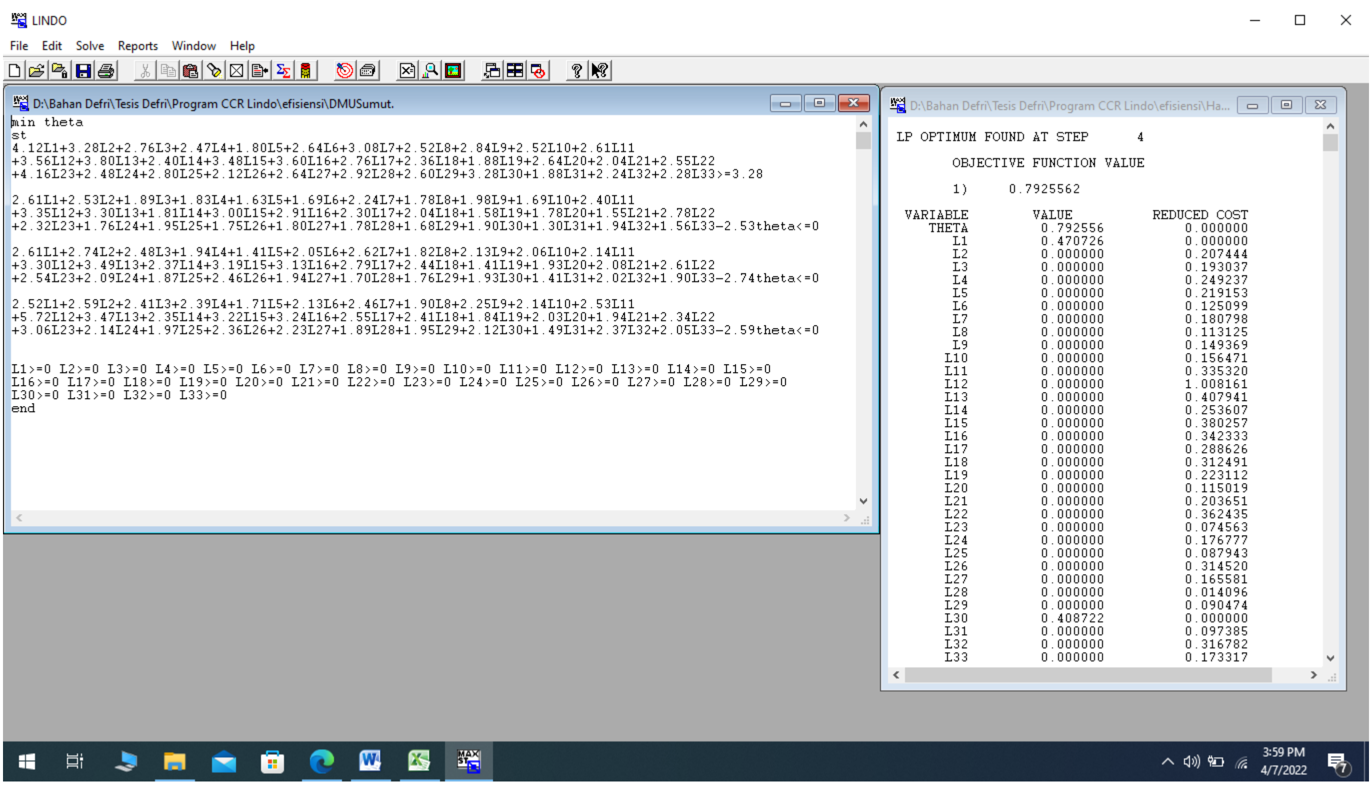

Figure 1. Program interface and results of DMU efficiency scores of North Sumatra province

The efficiency value obtained for North Sumatra Province DMU $\theta_0^* = 0.79$ which means that the efficiency value is 79%. With a weight value of $\lambda_1 = 0.470726$ and a weighted value of $\lambda_{30} = 0.408722$, this implies that the province of North Sumatra must refer to the Province of Aceh and Maluku Province, which means that the value of the input variable at the efficiency level is $0.470726 \begin{bmatrix} 2.61 \\ 2.61 \\ 2.52 \end{bmatrix} + 0.408722 \begin{bmatrix} 1.90 \\ 1.93 \\ 2.12 \end{bmatrix} = \begin{bmatrix} 1.22 \\ 1.22 \\ 1.18 \end{bmatrix} + \begin{bmatrix} 0.77 \\ 0.78 \\ 0.86 \end{bmatrix} = \begin{bmatrix} 1.99 \\ 2.00 \\ 2.04 \end{bmatrix}$.

and the value of the output variable $0.470726[4.12] + 0.408722[3.28] = [1.93] + [1.34] = [3.27]$, this indicates that if North Sumatra Province DMU is expected to be efficient, then the value of the input variable must change from $\begin{bmatrix} 2.53 \\ 2.74 \\ 2.59 \end{bmatrix}$ to $\begin{bmatrix} 1.99 \\ 2.00 \\ 2.04 \end{bmatrix}$ and the value of the output variable must change from $[3.28]$ to $[3.27]$.

E. CONCLUSION AND SUGGESTION

The DEA model developed by changing the DEA-CCR multiplier form into the DEA-CCR model envelopment form is a way to obtain the weight value of each DMU used as a reference. This modified DEA-CCR model can be used in terms of optimally determining efficiency level values, for inefficient DMUs by referring to efficient DMUs, optimally determining super-efficiency values and can also be used in terms of optimally determining effectiveness and productivity values and the formation of clusters with a certain number based on references.

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