Model Evaluation To Measuring Efficiencies of ICT Development In Indonesia Region Using DEA

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Abstract. ICT Pura or digital city is a program designed by the Indonesian government with the main objective is to determine the level of readiness of each district and city in each province in the era of digital economy. It is necessary to evaluate whether a city or a region that was successfully managing ICT better than other city and significantly contributes to the communities and living systems. Data envelopment analysis (DEA) is a well known technique to estimate efficiency and returns to scale through the construction of a best practice frontier, based on non-parametric mathematical programming approach. This paper addresses DEA BCC method to get index of efficiencies for all region in Indonesia covered by ICT Pura. Numerical result is given.

1. Introduction
During these last few years, the Indonesian Government had made an effort to develop nationally the application of information-communication in public sectors, called ICT-Pura. ICT Pura could mean a "ICT’s City" or "Digital City". It is given to a city that was successfully managing ICT better than other city and thus significantly contributes to the communities of environment and living systems.

ICT Pura program is designed by the Indonesian government to meet several main objectives, which is to determine the level of readiness of each district and city in each province in the era of digital economy which will be begin in 2015, to measure the size of the real gap between the target and actual conditions on every district and city to be prepared in a national strategy. It is also to provide motivation, support, incentives, and appreciation for the District and the City, for their hard effort and their preparation to face the era of the digital society through a variety of program development and implementation of ICT in the respective areas.

ICT Pura is expected to show the real situation of the city’s readiness for the challenge of ICT development, including measuring the amount of technology gap between regions and city. So from the real world conditions, ICT Pura will represent the strengths, weaknesses, challenges, and opportunities of the city, and it can be a step to plan the next strategy for ICT problem and optimization from the previous ICT Pura result.

Performance measurement and benchmarking are important tools for improvement in highly competitive and rapidly changing business environment of our era. Clearly, performance measurement concept is related with the measurement and improvement of efficiency to a great extent. Investigation and further analysis of worst and best performers in a business environment play a key role in deriving useful information to understand the current state of the processes and to identify the opportunities for improvement in efficiency. Several models methods can be found in Economics and Operational Research (OR) literature attempting to assess efficiency of different types of business operations, units or processes, called Data Envelopment Analysis (DEA).
DEA evaluates the relative performances of comparable units having the authority to make decisions. These units are called decision making units (DMUs). In DEA model it is necessarily to have multiple input and output quantities of DMUs. The model can be formulated as a linear program. Each DMU is considered one by one and a linear program is solved for each DMU. The efficiency of a DMU is defined as the ratio of weighted outputs to weighted inputs. These weights are positive decision variable of the linear program. When a DMU is under consideration, DEA maximizes the efficiency ratio of that DMU by changing the weights of inputs and outputs. There is only one constraint type in standard DEA, none of the DMUs can be more efficient than 100%. Weighted outputs of a DMU cannot be more than weighted inputs of that DMU. DEA approach is based on the original work [1] and became popular with the work [2]. Standard DEA models only use the input and output quantities of DMUs. The efficiency of a DMU is measured relative to all other DMUs with the simple restriction that all DMUs lie on or below an efficient frontier [3].

An interactive DEA procedure (IDEA) was developed by [4]. IDEA incorporates the DM preference information to DEA in an iterative manner by setting minimum (maximum) acceptable levels of outputs (inputs). The authors illustrated IDEA model in the assessment of physics departments of UK Universities. [5] introduced the value efficiency analysis approach. By this approach, DEA uses the preference information of DM and assigns efficiency scores by using the estimated value function of DM. [6] introduced a systematic approach for the performance analysis of academic research in R&D institutions and universities using value efficiency analysis.

Reference [7] analyzed the policy effectiveness of player teams in a business game. Firstly, the efficient DMUs are determined by DEA. Afterwards, input weights are restricted since the author knows the policies of teams, i.e. the importance of inputs. Restrictions are made with constraints such as the weight of first input is not less than that of second input or the weight of first input is not less than 20% of the sum of all input weights. By introducing weight restrictions in DEA, some efficient DMUs become inefficient. The author classifies inefficiency as technical inefficiency and policy inefficiency. Technical inefficiency is the inefficiency of DMU in DEA model. Policy inefficiency is the difference of efficiency values of DMU in DEA model and weight restricted DEA model. Since this difference is due to the inefficient policy of the DMU.

A general analysis of DEA models is made by [8]. In this study DEA models are classified and new DEA approaches are shown with the use of multi criteria decision making approaches [9].

Both articles have represented different reviews of DEA models and approaches.

DEA is used in efficiency, effectiveness and/or performance analysis of banks and bank branches by [10][11] [12]. Measuring efficiency for public service with DEA is proposed by [13]. The application of DEA in transport sector is widespread, particularly in the evaluation of airports, ports, railways and urban transport companies [14].

Reference [15] use DEA to evaluate suppliers performance and segment suppliers. They develop DEA with chance constrained due to restriction imposed to fulfill on-time delivery. They show that there are statistically significant relationships between the dimensions of information sharing by the buying firm and the classification of supplier firms at varying level of on-time delivery performance risk. In evaluating hotel performance using DEA was proposed by [16]. DEA use as the input units are operations, marketing and environmental capabilities, the outputs are diversification strategy on performance of hotel industry. Another application of DEA in hotel efficiency is proposed [17]. Reference [18] investigate to evaluate a problem in supply chain management called Supplier Total Cost of Ownership (TCO). In order to analyze the supplier performance (or efficiency), they use DEA. The result they get efficiency indexes and ranking of suppliers, while requiring substantially less effort to perform the analysis. Reference [19] propose DEA to analyze comparative performance of airline strategic alliances.

2. Data Envelopment Analysis

In general, methods of efficiency measurement are based upon the estimation of a production frontier and can be classified into two basic groups as parametric and non-parametric approaches. Parametric frontiers are based on specific functional forms and can be either deterministic or stochastic.
non-parametric efficiency evaluation side. Data Envelopment Analysis (DEA) is a well established method aiming to identify relative efficiency. Decision Making Units (DMUs) producing multiple outputs through the use of multiple inputs. It does not require any assumptions about the functional form. The efficiency of a DMU is measured relative to all other DMUs with the simple restriction that all DMUs are members of a production possibility set and they lie on or below an efficient frontier. Efficiency can be simply defined as the ratio of output to input. More output per unit of input reflects relatively greater efficiency. If the greatest possible output per unit of input is achieved, a state of absolute or optimum efficiency has been achieved and it is not possible to become more efficient without new technology or other changes in the production process.

Let there are \( n \) DMU to be evaluated, each DMU has \( m \) input and \( s \) output. We can write \( x_{ij} (i = 1, 2, \ldots, m) \) and \( y_{rj} (r = 1, \ldots, s) \), respectively, as input data and output data from DMU \( j \), \( j = 1, \ldots, n \). The efficiency of DMU \( j \) can be formulated as

\[
\max h_0 = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}
\]

(1)

where \( u_r \) and \( v_i \) are the weight of, respectively, \( r \)th output and \( i \)th input.

The efficiency of DMU can now be found from the following solution of a linear programming problem

\[
\begin{align*}
\max h_0 &= \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \\
\text{s.t.} & \quad \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}} \leq 1, \quad j = 1, \ldots, n \\
& \quad u_r, v_i \geq 0, \quad r = 1, \ldots, s; \quad i = 1, \ldots, m
\end{align*}
\]

(2)

(3)

(4)

where subscript 0 is assigned for the DMU being evaluated. \( x_{ij} \) is the \( i \)th input of DMU \( j \) and \( x_{ij} > 0 \), \( i = 1, 2, \ldots, m \) and \( j = 1, 2, \ldots, n \). Coupled with that, \( y_{rj} \) is the \( r \)th output being observed of DMU \( j \) and \( y_{rj} > 0 \) for \( i = 1, 2, \ldots, m \) and \( j = 1, 2, \ldots, n \). The decision variables for the problem are \( u_r \) and \( v_i \) representing weight values as the solution of problem (2, 3, 4). However the problem (2, 3, 4) has unbounded solution, as if \( u^* \) and \( v^* \) are the optimal solution, then for every \( \alpha > 0 \), \( \alpha u^* \) and \( \alpha v^* \) are optimal. Using transformation of Charnes-Cooper, then the representative solution of \( (u,v) \) can be chosen with condition:

\[
\sum_{i=1}^{m} v_i x_{i0} = 1
\]

(5)

Therefore we can get an equivalent linear programming of Problem (2, 3, 4) as a fractional programming. If we take the numerator of the problem equals to one then we will get an equivalent linear program, which can be written as:

\[
\begin{align*}
\max h_0 &= \sum_{r=1}^{s} u_r y_{r0} \\
\text{s.t.} & \quad \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, 2, \ldots, n \\
& \quad \sum_{i=1}^{m} v_i x_{ij} = 1 \\
& \quad u_r, v_i \geq 0, \quad r = 1, \ldots, s; \quad i = 1, \ldots, m
\end{align*}
\]

(6)

(7)

(8)

(9)

Linear programming stated as Problem (6, 7, 8, 9) is called as CCR, from Charnes-Cooper-Rhodes (Multiplier model) with input-output orientation. Maximizing is carried out by choosing between “virtual” multiplier (weight values) \( u \) and \( v \) which can give a result of the maximum rate of ratio “virtual” output and “virtual” input. Such a problem can be formulated as a linear program for each DMU, written mathematically with the following model.

\[
\begin{align*}
\theta_0^* = \min & \quad \theta_0 \\
\text{s.t.} & \quad \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, \quad r = 1, 2, \ldots, s \\
& \quad \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_0 x_{i0}, \quad i = 1, 2, \ldots, m
\end{align*}
\]

(10)

(11)

(12)
\[
\lambda_j \geq 0, \quad j = 1, 2, \ldots, n
\]

(13)

Problem (10, 11, 12, 13) can give an optimal solution \( \theta^*_0 \), as the value of efficient. It is called technical efficient or CCR efficient for a particular DMU \( \theta \) (envelopment model). In order to get the overall efficiency of DMU, it is necessarily to repeat the process for each DMU \( \theta_j, \quad j = 1, 2, \ldots, n \). The value of \( \theta \) is always less than or equal to one.

Now, we need to get the result of DEA model in terms of variable return to scale value. This result can be achieved if Problem (10 - 13) can be modified as convex form by inserting additional constraint \( \sum_{j=1}^{n} \lambda_j = 1 \).

Now, the problem can be expressed as:

\[
\theta^*_0 = \min \theta_0
\]

s.t. \( \sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{r0}, \quad r = 1, 2, \ldots, s \) \tag{15}

\( \sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta_0 x_{i0}, \quad i = 1, 2, \ldots, m \) \tag{16}

\( \sum_{j=1}^{n} \lambda_j = 1 \) \tag{17}

\( \lambda_j \geq 0, \quad j = 1, 2, \ldots, n \) \tag{18}

The BCC input-oriented model can be expressed in the following equations, where \( x_i \) and \( y_r \) are inputs and outputs, and \( s^*_{-i} \) and \( s^*_{-r} \) are the corresponding slacks:

\[
\theta^*_0 = \min \theta_0 - \varepsilon (\sum_{j=1}^{n} s^-_{-i} + \sum_{r=1}^{s} s^-_{-r})
\]

s.t. \( \sum_{j=1}^{n} \lambda_j y_{rj} - s^*_{-r} = y_{r0}, \quad r = 1, 2, \ldots, s \) \tag{19}

\( \sum_{j=1}^{n} \lambda_j x_{ij} + s^*_{-i} = \theta_0 x_{i0}, \quad i = 1, 2, \ldots, m \) \tag{20}

\( \sum_{j=1}^{n} \lambda_j = 1 \) \tag{21}

\( \lambda_j \geq 0, \quad j = 1, 2, \ldots, n \) \tag{22}

3. Problem Formulation

The research is carried out using the flow of mathematical modeling based on mapping process and the calculation of ICT Pura index of the whole Districts/Cities in Indonesia. The process had been done by the Indonesian Government in year 2011 up to 2013. The results are used as a basis to present “ICT Pura Award” to the Districts and Cities, for their efforts to develop communication and information technology in their regions. The index results can be formulated as a mathematical model. From the model we would be able to obtain four dimension treated as variables of the efficiency measurement of creating and developing ICT at the District/Cities, using DEA. These four dimensions are: ICT Use (Intensity), ICT Readines (Infrastructure), ICT Capability (Skills) dan ICT Impact (Outcomes).

4. Calculating Index

ICT Pura index can be said as an indicator to describe the level of readiness of a District/City in Indonesia facing or adapting with the digital community environment. Referring to ITU (International Telecommunication Union), WSIS (World Summit of Information Society) and The World Bank Institute the paradigm for calculating index can be shown in Figure 1.
The Index of ICT Pura can be found from Eq. (14)

\[
\text{Index}_{\text{ICTPura}} = \text{NR}_{\text{CI}} \times 25\% + \text{NR}_{\text{IU}} \times 40\% + \text{NR}_{\text{RI}} \times 20\% + \text{NR}_{\text{II}} \times 15\%
\]

where

- \( \text{NR}_{\text{CI}} \) = the average value of component ICT Capability
- \( \text{NR}_{\text{IU}} \) = the average value of component ICT Usage
- \( \text{NR}_{\text{RI}} \) = the average value of component ICT Readiness
- \( \text{NR}_{\text{II}} \) = the average value of component ICT Impact

According to the scoring system used in the mapping questionnaire, the value of ICT Pura Index is in the range of 0 to 5. The meaning of each index is described in Table 1.

| Index | Description | Score |
|-------|-------------|-------|
| 0     | City/District not ready at all | (1-mula) |
| 1     | City/District just started     | (1-pratama) |
| 2     | City/District almost ready     | (1-muda) |
| 3     | City/District ready            | (1-madya) |
| 4     | City/District ready, and able to compete | (1-utama) |
| 5     | City/District ready, and being far ahead | (1-paripurna) |

The results of ICT Pura Index for the year 2011, 2012 and 2013 for Districts/Cities around can be found in Table 2.

| No. | DMU Province       | Capability 25\% | Usability 40\% | Readiness 20\% | Impact 15\% | \( Ix_{\text{ICTPura}} \) |
|-----|---------------------|-----------------|----------------|----------------|--------------|-----------------|
| 1   | Aceh                | 2.69            | 1.93           | 2.29           | 2.99         | 2.34            |
| 2   | Sumater Utara       | 2.80            | 2.38           | 2.74           | 2.92         | 2.62            |
| 3   | Sumatera Barat      | 2.51            | 1.87           | 2.31           | 2.51         | 2.22            |
| 4   | Riau                | 2.52            | 1.81           | 2.08           | 2.20         | 2.12            |
| 5   | Kep. Riau           | 2.57            | 1.92           | 2.42           | 2.57         | 2.29            |
| 6   | Jambi               | 1.74            | 1.45           | 1.53           | 1.92         | 1.63            |
| 7   | Sumatera Selatan    | 2.27            | 1.77           | 2.09           | 2.40         | 2.06            |
| 8   | Bengkulu            | 2.46            | 1.78           | 2.13           | 2.46         | 2.12            |
| 9   | Lampung             | 2.21            | 1.83           | 1.93           | 2.57         | 2.06            |
| 10  | Kep. Bangka Belitung| 2.55            | 1.88           | 2.26           | 3.00         | 2.30            |
| 11  | DKI Jakarta         | 3.02            | 2.41           | 2.07           | 3.77         | 2.73            |
| 12  | Jawa Barat          | 2.92            | 2.46           | 2.86           | 3.05         | 2.73            |
| 13  | Jawa Tengah         | 3.10            | 2.43           | 2.86           | 3.13         | 2.79            |
| 14  | Banten              | 2.74            | 1.86           | 2.40           | 2.62         | 2.29            |
| 15  | Jawa Timur          | 3.06            | 2.49           | 2.79           | 3.28         | 2.66            |
In this paper, we propose the calculation to get the level of efficiency of developing ICT in each province (DMU), using BCC DEA of Problem (14, 15, 16, 17, 18).

\[
\theta_0 = \min \theta_0
\]

\[\sum_{j=1}^n \lambda_j y_{rij} \geq y_{ref}, \quad r = 1, 2, \ldots, s\]  \hspace{1cm} (26)

\[\sum_{j=1}^n \lambda_j x_{ij} \leq \theta_0 x_{io}, \quad i = 1, 2, \ldots, m\]  \hspace{1cm} (27)

\[\sum_{j=1}^n \lambda_j = 1\]  \hspace{1cm} (28)

\[\lambda_j \geq 0, \quad j = 1, 2, \ldots, n\]  \hspace{1cm} (29)

The result of the efficiency level for all Province in Indonesia and the Category for each Province as shown is Table 3.

| No. | DMU Province       | Capability X1 | Usability X2 | Readiness X3 | Impact Y | Efficiency level | Category |
|-----|--------------------|----------------|--------------|--------------|----------|------------------|----------|
| 1   | Aceh               | 2.69           | 1.93         | 2.29         | 2.99     | 86.72%           | I-Madya  |
| 2   | Sumatera Utara    | 2.80           | 2.38         | 2.74         | 2.92     | 67.55%           | I-Madya  |
| 3   | Sumatera Barat    | 2.51           | 1.87         | 2.31         | 2.51     | 73.67%           | I-Madya  |
| 4   | Riau               | 2.52           | 1.81         | 2.08         | 2.20     | 74.10%           | I-Madya  |
| 5   | Kep. Riau          | 2.57           | 1.92         | 2.42         | 2.57     | 72.12%           | I-Madya  |
| 6   | Jambi              | 1.74           | 1.45         | 1.53         | 1.92     | 94.50%           | I-Mada   |
| 7   | Sumatera Selatan  | 2.27           | 1.77         | 2.09         | 2.40     | 77.10%           | I-Madya  |
| 8   | Bengkulu           | 2.46           | 1.78         | 2.13         | 2.46     | 77.07%           | I-Madya  |
| 9   | Lampung            | 2.21           | 1.83         | 1.93         | 2.57     | 75.67%           | I-Madya  |
| 10  | Kep. Bangka Belitung | 2.55       | 1.88         | 2.26         | 3.00     | 89.53%           | I-Madya  |
| No. | Province          | M | P | C | Efficiency Level |
|-----|------------------|---|---|---|------------------|
| 11  | DKI Jakarta      | 3.02| 2.41| 2.07| 3.77| 100.00% | I-Madya          |
| 12  | Jawa Barat       | 2.92| 2.46| 2.86| 3.05| 70.34%  | I-Madya          |
| 13  | Jawa Tengah      | 3.10| 2.43| 2.86| 3.13| 74.32%  | I-Madya          |
| 14  | Banten           | 2.74| 1.86| 2.40| 2.62| 74.76%  | I-Madya          |
| 15  | Jawa Timur       | 3.06| 2.49| 2.79| 3.28| 78.21%  | I-Madya          |
| 16  | DI Yogyakarta    | 3.32| 2.68| 3.13| 3.32| 74.08%  | I-Utama          |
| 17  | Bali             | 3.04| 2.17| 2.87| 2.90| 73.22%  | I-Madya          |
| 18  | Nusa T. Barat    | 2.64| 1.89| 2.29| 2.46| 72.58%  | I-Madya          |
| 19  | Nusa T. Timur    | 1.82| 1.44| 1.41| 1.97| 94.42%  | I-Madya          |
| 20  | Kalimantan Barat | 1.99| 1.42| 1.74| 1.91| 94.37%  | I-Madya          |
| 21  | Kalimantan Tengah| 2.16| 1.60| 1.92| 2.39| 85.22%  | I-Madya          |
| 22  | Kalimantan Selatan| 2.12| 2.02| 2.11| 2.50| 72.64%  | I-Madya          |
| 23  | Kalimantan Timur | 2.65| 2.04| 2.19| 3.37| 99.63%  | I-Madya          |
| 24  | Sulawesi Utara   | 2.00| 1.42| 1.58| 2.71| 99.26%  | I-Madya          |
| 25  | Sulawesi Tengah  | 2.43| 1.59| 1.92| 2.56| 87.01%  | I-Madya          |
| 26  | Sulawesi Selatan | 2.86| 2.07| 2.46| 2.90| 76.75%  | I-Madya          |
| 27  | Sulawesi Tenggara| 2.11| 1.42| 1.62| 2.69| 98.51%  | I-Madya          |
| 28  | Gorontalo        | 2.42| 1.98| 1.79| 2.77| 74.04%  | I-Madya          |
| 29  | Sulawesi Barat   | 2.01| 1.58| 1.76| 2.63| 88.09%  | I-Madya          |
| 30  | Maluku           | 1.54| 1.40| 1.21| 2.70| 100.00% | I-Madya          |
| 31  | Maluku Utara     | 2.19| 1.50| 1.75| 2.37| 90.75%  | I-Madya          |
| 32  | Papua            | 2.36| 1.85| 1.98| 2.70| 75.68%  | I-Madya          |
| 33  | Papua Barat      | 1.75| 1.34| 1.39| 2.19| 100.00% | I-Madya          |

From Table 3, we should be able to observe that there is a discrepancy between Level of Efficiency and the Category of a Province obtained. For example, Aceh Province has the ICT Pura Index 2.34 and Category I-Madya, meaning that this province is in category ready to develop, although the efficiency level is only 86.72%. Yogyakarta obtains the highest Index, 3.03. Therefore this province belongs to Category I-Utama. Unfortunately, the level of efficiency is only 74.08%, worse than Aceh. However, it is different with Maluku province, from the Table 5 we can see that this province has the least ICT-Pura index, which is 1.59 with Category I-Madya. However, the level of efficiency to develop its ICT is 100%.

Figure 2 describes graphically the ICT-Pura index and the level of efficiencies for each provinces.

![Figure 2. Results for ICT-Pura index and Level of Efficiency of each Provinces.](image-url)
5. Conclusion
In order to be able to compete in the “Digital Economic” era, each province in Indonesia has been urged to develop its potential in the field of Information-Communication-Technology. Indonesia has given motivations to fulfill this needs through what is called ICT Pura. This paper presents a way to see the readiness of each province in Indonesia for the Digital Economy era by measuring the level of efficiency via DEA model. Each province is called DMU. The results obtained show that it is not enough just to use Category to see the readiness of each province, but we need level of efficiency, in such a way the local Government should be able to detect the weakness of his/her Province.

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