

A Study on the evaluation of the ICT development indexes and some results

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Abstract— The ICT Development Index (IDI) functions as an established tool for assessing the digital divide and facilitating comparisons of ICT performance within and between countries. Information entropy, representing the level of uncertainty in a random variable, can be applied across various fields, including information and communication technology (ICT). When designing data analysis using information entropy, it is essential to observe, evaluate, and utilize metrics derived from this method. The proposed methodology aims to allocate weights to the indicators within the ICT Development Index for country ranking. To assess the efficacy of this methodology, we explored its potential applications in evaluating indexes. Our model incorporates an innovative approach that combines the entropy weight coefficient method with the correlation coefficient weighting method. We present the evaluation results of the integrated calculation method in Mongolia.

Keywords— ICT indicators, entropy weight, IDI, correlation coefficient weight, ICT development index

I. INTRODUCTION

Since 2009, the International Telecommunications Union (ITU) has annually released the IDI. This index serves as a valuable resource for policymakers and researchers in evaluating the efficacy of policies and initiatives geared toward promoting ICT development. It enables the benchmarking of progress and the exchange of best practices among countries [1][2]. Through quantitative metrics and benchmarks, the IDI offers an objective assessment of international performance. Decision-makers find it to be an indispensable tool for measuring ICT growth and progress globally [2][3]. Additionally, the IDI acknowledges the convergence of technology and the emergence of new technologies, making it effective in assessing the impact of ICT on society and the economy [4-6]. ITU's Council noted in September 2023 during the annual meetings, that the IDI methodology, the Version 3 document, was finalized, now called Version 3.1 with 10 indicators, and has been submitted for approval by Member States [7].

II. METHODOLOGY FOR INDEX EVALUATION

Within this section, we will introduce the formulation of an integrated evaluation model for the IDI. The subsequent subsection will furnish an outline of several fundamental theories, followed by an in-depth explanation of the proposed integrated algorithm.

A. Entropy weighting method

The concept of information entropy measures the amount of information that can be obtained from a source of random data. It was introduced by Shannon [8-16]. The entropy weighing method is a process used to calculate index values in analyses conducted under objective conditions. It enables the evaluation of intent, degree of order, and efficiency by employing entropy estimation of the information. The entropy weighting approach contributes to enhancing the objectivity of rank lists [13][14][16-27].

B. Correlation coefficient weighting method

To examine the correlation among indicators of ICT development, the correlation coefficient (CC) formula was applied. Correlation analysis, a quantitative analytical tool, is employed to assess the extent of the relationship between independent and dependent variables [13][24][28].

C. Proposed weighting method

This subsection aims to provide a detailed description of the proposed integration algorithm.

The following are the specific steps:

- 1) Assuming that there are m additional elements that require measurement, and we have an algorithm for measuring n objects, we must create an evaluation matrix for the evaluation model.

$$X_{ij} = (x_{ij})_{m \times n} \quad (1)$$

The notation x_{ij} represents the elements of a matrix, while the value of the i^{th} indicator of the j^{th} sample is denoted as x_{ij} .

- 2) The matrix needs to be normalized using the following operations:

$$d_{ij} = \frac{x_{ij}}{\max x_{ij}} \quad (2)$$

The resulting normalization matrix is obtained as follows:

$$D_{ij} = (d_{ij})_{m \times n} \quad (3)$$

- 3) The related weight of x_{ij} is:

$$P_{ij} = (p_{ij})_{m \times n}$$

$$p_{ij} = \frac{d_{ij}}{\sum_{i=1}^m d_{ij}} \quad (4)$$

- 4) Equation (5) represents Shannon's information entropy for the i^{th} indicator of the matrix, where m is the number of indicators and n is the number of objects.

$$E_i = -\frac{1}{\ln(n)} \sum_{j=1}^n p_{ij} \ln p_{ij} \quad (5)$$

To standardize the value of E_i and ensure that $0 < E_i < 1$.

- 5) The equation for representing the entropy weight is given below:

$$W_{ei} = \frac{1 - E_i}{m - \sum_{i=1}^m E_i} \quad (6)$$

- 6) This results in a symmetrical matrix of size $m \times m$ with a generic element denoted by r_{ik} in a matrix of R . To determine r_{ik} , follow the steps below:

$$r_{ik} = \frac{n \sum x_{ij} y_{ik} - (\sum x_{ij})(\sum y_{ik})}{\sqrt{n \sum x_{ij}^2 - (\sum x_{ij})^2} \cdot \sqrt{n \sum y_{ik}^2 - (\sum y_{ik})^2}} \quad (7)$$

$i, k = 1, 2, \dots, m$

- 7) The symmetric matrix must be used to determine the correlation coefficient.

$$R = (r_{ik})_{m \times m}$$

$i, k = 1, 2, \dots, m$ (8)

We utilize the sum function to estimate the level of disagreement caused by the index function f_i in comparison to the other indexes. This implies that the alternatives with higher discordant scores on criteria f_i and f_k should receive a lower r_{ik} rating.

- 8) The sum vector can be normalized to obtain the weight of the CC:

$$W_{cci} = \frac{\sum_{k=1}^m (1 - r_{ik})}{\sum_{i=1}^m \sum_{k=1}^m (1 - r_{ik})} \quad (9)$$

$i = 1, 2, \dots, m$

CC weight W_{cci} can be obtained with Equation (9).

- 9) To find the weight W_{eci} by utilizing the output of Equation (6) and (9) and performing the calculation indicated in Equation (10).

$$W_{eci} = \frac{W_{ei} \cdot W_{cci}}{\sum_{i=1}^m W_{ei} \cdot W_{cci}} \quad (10)$$

The proposed weighting method utilizes the CC weight method grounded in the principles of entropy.

III. ASSESSMENT OF INDICATORS IN THE CASE OF ICT DEVELOPMENT INDEX

A. Selected indicators of IDI

The IDI was established with the purpose of gauging the advancement of the information and communication technology sector. Published by the ITU, this composite indicator was active from 2009 to 2017 but was discontinued in 2018 due to challenges related to the availability and quality of data [7]. The IDI was established with the purpose of gauging the advancement of the ICT sector. Published by the ITU, this composite indicator was active from 2009 to 2017 but was discontinued in 2018 due to challenges related to the availability and quality of data [7]. Table 1 shows indicators of IDI by methodology of the ICT Development Index Version 3.1, ITU.

TABLE 1. INDICATORS OF IDI [7]

Universal connectivity	
X1	Proportion of individuals who used the Internet (from any location) in the last 3 months
X2	Proportion of households with Internet access at home
X3	Active mobile-broadband subscriptions per 100 inhabitants
Meaningful connectivity – Infrastructure	
X4	Percentage of the population covered by at least a 3G mobile network
X5	Percentage of the population covered by at least a 4G/LTE mobile network
X6	Mobile broadband Internet traffic per mobile broadband subscription (GB)
X7	Fixed broadband Internet traffic per fixed broadband subscription (GB)
Meaningful connectivity – Affordability	
X8	Mobile data and voice high-consumption basket (as a % of GNI per capita)
X9	Fixed-broadband Internet basket price (as % of GNI per capita)
Meaningful connectivity – Device	
X10	Percentage of individuals owning a mobile phone

Indicators (X1) through (X3) denote universal connectivity, while (X4) to (X10) signify meaningful connectivity. Specifically, (X4) to (X7) focus on infrastructure, (X8) to (X9) assess affordability, and (X10) gauges device ownership.

B. Correlation analysis

Correlation analysis stands as a crucial statistical tool in the development of composite indicators. By elucidating the statistical relationships among the indicators under consideration for inclusion, it offers an initial insight into the robustness of an index and potential issues related to internal consistency. Correlation analysis can also provide insights into the weighting process and the arrangement of indicators. Table 2 displays the correlation coefficients related to the indicators of capital city and aimags in Mongolia. Mongolia is divided into 21 aimags or provinces. In general, the correlation coefficients exhibit the anticipated signs within the chosen set of indicators. The anticipated weak correlation between the two affordability indicators and the remaining indicators is also in line with expectations, given that these indicators are measured in opposite directions; lower prices correspond to a better

situation. The indicators within the universal connectivity category exhibit positive and moderate to strong correlations with each other. The survey-based indicators demonstrate the highest degree of similarity, while the somewhat weaker coefficients between fixed and mobile broadband penetration indicators suggest that these two technologies complement each other. All correlations are stronger than 0.183 in both pillars.

TABLE 2. PEARSON CORRELATION COEFFICIENT MATRIX OF SELECTED INDICATORS OF IDI

	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10
X1	1	0.614	0.435	0.391	0.438	0.315	0.376	0.183	0.217	0.914
X2	0.614	1	0.672	0.716	0.688	0.315	0.376	0.391	0.509	0.525
X3	0.435	0.672	1	0.72	0.789	0.506	0.546	0.528	0.538	0.358
X4	0.391	0.716	0.72	1	0.914	0.455	0.536	0.525	0.394	0.354
X5	0.438	0.688	0.789	0.914	1	0.462	0.537	0.523	0.387	0.359
X6	0.315	0.641	0.506	0.455	0.462	1	0.638	0.388	0.54	0.201
X7	0.376	0.661	0.546	0.536	0.537	0.638	1	0.41	0.6	0.207
X8	0.183	0.391	0.528	0.525	0.523	0.388	0.41	1	0.41	0.184
X9	0.217	0.509	0.538	0.394	0.387	0.54	0.6	0.41	1	0.437
X10	0.914	0.525	0.358	0.354	0.359	0.201	0.207	0.184	0.437	1

Likewise, the moderate correlation observed between the two survey-based measures and the penetration measures based on administrative data indicates complementarities between these two approaches. The strong positive correlation observed between the indicators measuring mobile broadband coverage with at least 3G and 4G/LTE technologies implies that these two indicators can be consolidated into a singular measure within the meaningful connectivity infrastructure category.

C. Analysis of selected indicators of IDI

Implementing the suggested weighting method results in indicators X9 and X10 emerging with the highest rank among the IDI indicators, signifying their development in ICT in the country. Conversely, indicators X5 and X7 attain the lowest rank.

TABLE 3. THE WEIGHTS AND RANK OF THE IDI INDICATORS

indicators	W_e	rank	W_{cc}	rank	W_{ec}	rank
X1	0.0103	9	0.1104	3	0.0115	9
X2	0.0411	8	0.0905	7	0.0493	8
X3	0.1388	3	0.0843	9	0.1280	2
X4	0.1466	2	0.0862	8	0.1260	3
X5	0.1363	4	0.0842	10	0.1198	4
X6	0.1363	5	0.1047	5	0.1171	5
X7	0.0003	10	0.0969	6	0.0003	10
X8	0.0642	7	0.1178	2	0.0634	7
X9	0.2620	1	0.1072	4	0.3145	1
X10	0.0642	2	0.1178	1	0.0701	6

Table 3 and Figure 1 show the weights and rank of the IDI indicators.

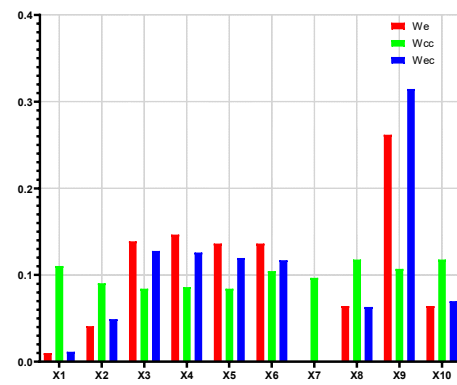


Figure 1. The weights of the IDI indicators

It appears that weights between indicators calculated by equations (6), (9), and (10) pillar scores in Figure 1, are generally favorable, with values ranging from 0.0003-0.262 for the W_e , from 0.0842-0.1072 for the W_{cc} , and from 0.0003-0.3145 for the W_{ec} . This suggests effective summarization of information from indicators into pillars.

D. Analysis of the IDI indicators of aimags

The outcomes of the entropy weight method reveal that Umnugovi aimag (0.0554) in the central region and Ulaanbaatar city (0.0421) attain the highest rank in IDI. Conversely, Bayan-Ulgii aimag (0.0413) in the western region and Bulgan aimag (0.0421) in the central region secure the lowest ranks.

TABLE 4. THE WEIGHTS AND RANK OF CAPITAL CITY AND AIMAGS

No	Aimag	W_e	rank	W_{cc}	rank	W_{ec}	rank
1	Bayan-Ulgii	0.0413	22	0.0358	21	0.0326	21
2	Govi-Altai	0.0447	12	0.0392	17	0.0387	16
3	Zavkhan	0.0445	13	0.0415	13	0.0407	13
4	Uvs	0.0435	18	0.0398	16	0.0382	17
5	Khovd	0.0443	15	0.0419	12	0.0409	12
6	Arkhangai	0.0434	20	0.0227	22	0.0218	22
7	Bayankhongor	0.0434	19	0.0372	19	0.0356	19
8	Bulgan	0.0421	21	0.0360	20	0.0335	20
9	Orkhon	0.0487	3	0.0564	3	0.0606	3
10	Uvurkhangai	0.0440	17	0.0388	18	0.0377	18
11	Khuvsgul	0.0443	16	0.0423	11	0.0413	11
12	Govisumber	0.0470	4	0.0563	4	0.0584	4
13	Darkhan-Uul	0.0470	5	0.0560	5	0.0580	5
14	Dornogovi	0.0465	6	0.0477	7	0.0489	7
15	Dundgovi	0.0443	14	0.0406	14	0.0397	15
16	Umnugovi	0.0554	1	0.0596	2	0.0728	1
17	Selenge	0.0454	9	0.0454	10	0.0454	9
18	Tuv	0.0455	8	0.0470	8	0.0471	8
19	Dornod	0.0463	7	0.0530	6	0.0541	6
20	Sukhbaatar	0.0449	11	0.0404	15	0.0400	14
21	Khentii	0.0451	10	0.0455	9	0.0453	10
22	Ulaanbaatar	0.0488	2	0.0638	1	0.0687	2

The normalized scores and rank of the IDI indicators of aimags are present in Table 4 and Figure 2.

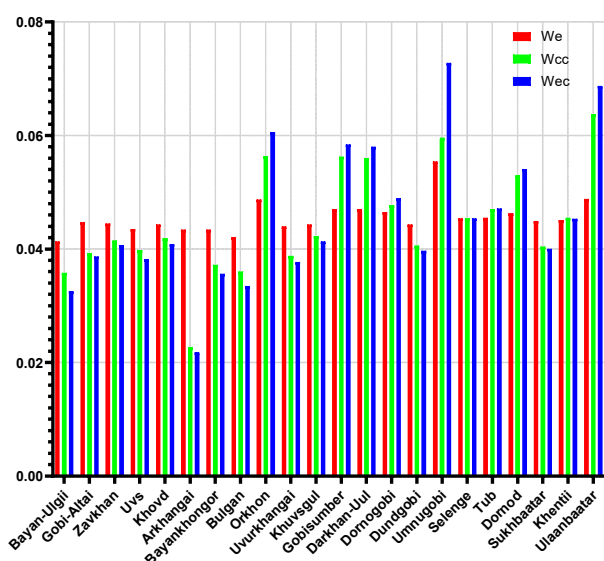


Figure 2. The weights of capital city and aimags

With the CC weight method, the results emphasize Umnugovi aimag (0.0728) as the highest in ICT development in the country, while Arkhangai aimag (0.0227) in the Khangai region ranks the lowest. Applying the proposed weighting method, Umnugovi aimag (0.0728) and Ulaanbaatar city (0.0687) emerge as the most developed in ICT in the country. Conversely, Arkhangai aimag (0.0413) in the Khangai region is identified as the least developed in terms of ICT development.

IV. CONCLUSIONS

The IDI indicators of aimags were analyzed using the CC weight method, entropy weight method, and the proposed method equation. The present study has assessed the levels of ICT development across capital city and 21 aimags by employing a composite result derived from ten selected indicators. The weight method has been utilized to scrutinize the IDI indicators of the aimags and ascertain the rank of regions within the study domain. Umnugovi aimag (0.078) in the central region attains the highest rank, while Ulaanbaatar city (0.0687) region secures the second rank for IDI in Mongolia. Nevertheless, Arkhangai (0.0218), Bayan-Ulgii (0.0326), and Bulgan (0.0335) aimags are situated at the lowest rank for IDI in Mongolia.

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