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Analysis of ICT Development Index Based on Entropy

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ABSTRACT: This paper discusses the determination of more advanced methods based on information theory and entropy. Such metrics, in ICT, are derived by observing, evaluating, and using the entropy-based method. The methodology proposed is to be developed as the weight of indicators in ICT, development index and sub-indexes and ranking them for the indicators for global, regions, and countries. Therefore, we investigate the availabilities of use determining the methodology of index evaluation. The method is an integration of a novel entropy-based approach that combined the entropy weight coefficient method, S-shaped diffusion stages of ICT's and the correlation coefficient weighting method. Evaluation results of the proposed method shows can define weights of ICT indicators in IDI.

KEYWORDS: ICT indicators, entropy, entropy weight

I. INTRODUCTION

A way of obtaining data was used in the design of any analysis based on the term called information entropy. Entropy, in information theory, is a function of a random variable's mean uncertainty. The information theory is a mathematical representation of the parameters and conditions that affect the processing of communication. The information theory was developed by Shannon to determine the fundamental constraints on compression and reliable data. Information theory is based on statistics and probability theory. Entropy weighing is a method that consists of monitoring values of the evaluation index under objective conditions, can determine the purpose and order degree and efficiency, referring to the information entropy estimate. The ICT Development Index (IDI) is an index that integrates eleven indicators into one benchmark, and it has been published annually since 2009. It is used for monitoring and comparing ICT development between countries over time [1,2]. It is now generally accepted that ICT plays an important part in the growth of society and the economy. The IDI was designed in 2008 by the International Telecommunications Union (ITU) and first presented in the 2009 edition of the "Report on Measuring the Information Society". It was developed in response to a request from Member States of the ITU to draw up a single ICT index [2,3]. IDI rates the success of the countries in terms of ICT infrastructure and uptake [4-8]. The ITU has not published the IDI in 2018 due to a number of data quality and quantity challenges that resulted from the change in the set of indicators included in the IDI, agreed in 2017 [9]. The ITU Secretariat recommends publishing the IDI for 2019 on the basis of the original methodology and set of indicators, rather than publishing it in any way [10,11]. Therefore, we used data from IDI 2017 and pre-2017.

II. RELATED WORK

The advent of ICT is deciding significant and profound changes in many areas of social and economic life. The life cycle of implementation of the technology usually occurs in S curve, as is the diffusion of innovations theory method. Mathematically, the S-curves can be drawn. S-curves can also be used in a nonmathematical, figurative, way to inspect and stages of many other technological phenomena [15-19]. IDI indicators that are based on S-shaped diffusion with impact, intensity, and readiness stages [15-19]. The entropy method is best general objective weighted method. Nevertheless, the entropy weighting method was not related to the interrelationship between the criteria such as the weighting methods criteria importance through inter-criteria correlation (CRITIC) [17] and weighing method integrating correlation coefficient and standard deviation (CCSD) [18]. These two methods are a similar integration of the correlation coefficient [18,19] of the metrics from a different perspective. The results of a comprehensive evaluation can differ significantly due to the different index weightings resulting from the subjective weighting method. Therefore, that is necessary to perform an analysis of weight [18,20] that can perform a quantifiable research of weight detail [21]. The combination weights can make objective weights compromise. In this paper we suggest a sub-index weight taking into account ICT indicator parameters for assessing the IDI. The proposed integrated entropy weighting method is an integration of a novel entropy-based approach that combined the entropy weight coefficient method, S-shaped diffusion stages of ICT's and the weighting method of correlation coefficient.

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III. THE PROPOSED INTEGRATED ENTROPY WEIGHTING METHOD AND METHODOLOGY

An integrated evaluation method for the ICT development index was developed in this section. The method integrates a proposed entropy weight, stages of diffusion of ICTs, and correlation coefficient weight method. The subsection gives a summary of several key theories, and the integrated methodology is finally explained.

A. *Entropy weight coefficient method:*

Information entropy determines the mean volume of information received from a stochastic source of data. The expected value of random variables is the entropy of information, thus becoming the sum of information collected. In 1948 paper called "A Mathematical Theory of Communication" Shannon [22-27] submitted the concept of information entropy. The data communication system's primary method is based on key elements such as data source, path, and receiver [24,27]. The entropy weighting approach makes rank lists more objectively [28]. This removes the subjectivity of the various parameters weights, and so the assessment results in the best represent the actual situation [29]. The weight of entropy is determined by the matrixes of judgment [23,28]. The method completed from a calculated items to avoid subjective opinion, in here the entropy weight was defined from Shannon's entropy theory [27,28], as. Specific steps are as follows:

(1) Suppose there are m number other items that must be measured [21]. There is an algorithm for measuring n objects. The evaluation method 's evaluating matrix needs to be set.

$$X_{ij} = (x_{ij})_{mxn} \quad \text{eq.(1)}$$

$$i = 1,2..., m;\ j = 1,2..., n$$

Where x_j is the elements of a matrix and the value of the i^{th}-indicator j^{th} sample.

(2) That needs normalization. Certain operations:

$$\begin{cases} d_{ij} = x_{ij} / max\ \ x_{ij}, positive\ \ indicators \\ d_{ij} = x_{ij} / min\ \ x_{ij}, negative\ \ indicators \end{cases} \quad \text{eq. (2)}$$

The new normalization matrix:

$$D_{ij} = (d_{ij})_{mxn} \quad \text{eq. (3)}$$

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

$$P_{ij} = (p_{ij})_{mxn}$$

$$p_{ij} = d_{ij} \Big/ \sum_{i=1}^{m} d_{ij} \quad \text{eq. (4)}$$

(4) Assume factors are estimated by m, estimates objects counted by n and forms a matrix $R_{ij}=(r_{ij})_{mxn}$. Eq. (5) describes Shannon's information entropy of the i^{th} evaluation matrix indicator:

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

Furthermore, k-positive constant, which defines $k=1/ln(n)$, which is a standardizing constant to preserve $0 < E_i < 1$.

(5) The entropy weight is:

$$w_i = \frac{1 - E_i}{n - \sum_{i=1}^{n} E_i} \quad \text{eq. (6)}$$

Those measurements of equations are used for weights of entropy. In analyze information entropy weight common is used those eq. (1-6). The entropy analyzes based on independent probability or independent each other of ICT indicators. In real situation all ICT indicators are influenced each other and dependent development stages of ICT.

B. *Diffusion stages of ICTs*

When assessing ICT is appropriate and accurate, and cost effective, it is easier to measure how other development factors of a country such as economic growth, and technical preparedness to progress forward are affected by it [19]. The following three stages of ICT country distribution.

Stage 1 - Readiness for ICT: Once a technology is implemented into countries or nations, a significant issue is the capacity of the people to embrace new technology.

Stage 2 - ICT intensity: As adaptation growth, the intensity of adaptation becomes more significant in ICT-related entities (for example, digital government initiatives, business to business and business-to-consumer e-commerce etc).

Stage 3 - Impact: In this stage, the growth in ICT investment and implementation activities are considered. It involves national level economic and business activities that are affected by the ICT related development [21].

This measurement guides us to discover possible measurement necessities for ICTs. The ICT spread processes between nations are dependent on basic infrastructure conditions of infrastructures that lead to various levels of intensity of adaptation in the digitalization process. The third dimension, i.e. the changes in social and economic structures, is concerned, the impacts have currently started to appear; hence any research in this regard will be misguided [13]. With this in mind we have given the highest priority to the indicators of readiness, and lower priority for digitalization assessment to the impact indicators. Since that precise value of the metrics cannot be determined at each point of ICT distribution, most acceptable using of non-parametric statistics is use of ranks rather than numeric values [14]. Nonparametric statistics imply that the population matches any parameterized distributions [15], and in most cases, is applied to populations that are ranked [14].

C. *Correlation coefficient weighting method*

Correlation coefficient [17] between the data of indicators fi of the appraisal data shown in eq.(7) [25,26]. That is a symmetrical matrix, with an element of mxm and a generic portion of r_{jk}, that is, R, where r_{jk} is determined using the following steps:

$$r_{jk}=\frac{n\sum x_{ij}y_{ik}-(\sum x_{ij})(\sum y_{ik})}{\sqrt{n\sum x_{ij}{}^{2}-(\sum x_{ij})^{2}}\cdot\sqrt{n\sum y_{ik}{}^{2}-(\sum y_{ik})^{2}}},\quad j,k=1,2,\dots,m \qquad \text{eq. (7)}$$

The correlation coefficient must be determined by the symmetric matrix.

$$R=\left(r_{jk}\right)_{mxm},\ j,.k=1,2,\dots,m \qquad \text{eq. (8)}$$

We take advantage of the sum function, which esteems a measurement of the dispute generated by index function f_j in relation to the remaining indices. That suggests the more cacophonous alternatives scores on criteria f_j and f_k should be assigned to the lower r_{jk} rating. Then the sum vector normalizes correlation coefficient weight can be obtained:

$$W_{cj}=\frac{\sum_{k=1}^{m}(1-r_{jk})}{\sum_{j=1}^{m}\sum_{k=1}^{m}(1-r_{jk})},\ j=1,2,\dots,m \qquad \text{eq. (9)}$$

Correlation coefficient weight W_c can be obtained with eq. (9).

D. *The proposed integrated entropy weighting method*

This subsection wants to introduce the weights of the proposed method. Setting of entropy, ICT diffusion stages, and weights of correlation coefficient as the estimation parameters in entropy resample matrices (see III.A), ICT diffusion stages (see III.B) and correlation coefficient (CC) (see III.C) weights with B x m dimensions, respectively. That is, new weight vectors of W_e, W_s and W_c will be determined at each resample time. Then bootstrap-entropy, bootstrap ICT diffusion stages, and bootstrap CC weights show as Wbe, Wbs and Wbc can be obtained by means of an average process, which formulates as follows:

$$W_{bej}=\frac{\sum_{b=1}^{B}W_{bej}/B}{\sum_{j=1}^{m}\left(\sum_{b=1}^{B}W_{bej}/B\right)},\ j=1,2,\dots,m \qquad \text{eq. (10)}$$

$$W_{bsj} = \frac{\sum_{b=1}^{B} W_{bsj} / B}{\sum_{j=1}^{m} \left(\sum_{b=1}^{B} W_{bsj} / B \right)}, \; j = 1,2,...,m \qquad \text{eq. (11)}$$

$$W_{bcj} = \frac{\sum_{b=1}^{B} W_{bcj} / B}{\sum_{j=1}^{m} \left(\sum_{b=1}^{B} W_{bcj} / B \right)}, \; j = 1,2,...,m \qquad \text{eq. (12)}$$

$$W_{besj} = \frac{W_{bej} \cdot W_{bsj}}{\sum_{j=1}^{m} W_{bej} \cdot W_{bsj}}, \; j = 1,2,...,m \qquad \text{eq. (13)}$$

$$W_{iescj} = \frac{W_{besj} \cdot W_{bcj}}{\sum_{j=1}^{m} W_{besj} \cdot W_{bcj}}, \; j = 1,2,...,m \qquad \text{eq. (14)}$$

The theory of entropy is a recognizable instrument for quantifying the volatility of coarse data. In addition, the effect of the association between measures worth also considering simultaneously. Measures of ICTs should permit appropriate, reliable, meaningful, and cost-effective evaluation of the degree to which ICTs are affecting, changing other attributes, its economic growth and technical readiness to catch further stages. At country level of survey, the driving three stages of dispersal of ICTs exist. The correlation coefficient weight method are thus integrated into the proposed method based on the entropy principle.

IV. ANALYSIS OF ICT DEVELOPMENT INDEX BASED ON PROPOSED METHOD

A. *ICT development index*

This section conducts an exhaustive evaluation of the IDI data of global region countries by ITU [3-6].The index is conceived to be represent and global changes occurring in countries at various rates of ICT growth. Hence, it relies on a small collection of data that can be developed in each countries at all rates of development with good confidence. To accept that ICTs could be enabler of development is essential to the conceptual meaning of IDI. The IDI consists of three sub-indexes, and eleven indicators, based on this conceptual structure [3-6]. (Table 1).

Table 1. ICT Development Index: indicators, weights

Indicators	code	%	W_{iesc}, %	Difference indicators percentages, %	W_{min}÷W_{max}, %	%	W_{iesc}, W_{min}÷W_{max} %	Difference sub-index Percentages, %
Access sub-index								
Fixed-telephone subscriptions per 100 inhabitants	A1	20	18.86	1.14	17.27÷21.98	40	44.04 42.77÷ 45.31	4.04
Mobile-cellular telephone subscriptions per 100 inhabitants	A2	20	19.77	0.23	15.29÷20.59			
International Internet bandwidth (bit/s) per Internet user	A5	20	16.13	3.87	11.75÷17.91			
Percentage of households with a computer	HH4	20	22.8	-2.8	22.72÷25.9			
Percentage of households with Internet access	HH6	20	22.44	-2.44	20.84÷25.76			
Usage sub-index								
Percentage of individuals using the Internet	HH7	33.33	36.81	-3.48	35.74÷39.7	40	26.21 25.75÷ 26.66	13.79
Fixed-broadband subscriptions per 100 inhabitants	A3	33.33	30.6	2.73	26.11÷32.46			
Active mobile-broadband subscriptions per 100 inhabitants	A4	33.33	32.59	0.74	31.57÷34.41			
Skills sub-index								
Mean years of schooling rate	S1	33.33	32.81	0.52	30.88÷34.25	20	29.75 28.47÷ 31.03	-9.76
Secondary gross enrolment ratio	S2	33.33	34.93	-1.6	34.63÷37.13			
Tertiary gross enrolment ratio	S3	33.33	32.2	1.13	30.7÷32.4			

The IDI indicator coefficients by ITU methodology are included reference value of indicators and Sub-indices weight and indicators weight in sub-indexes. Sub-indices of access and usage were given equal to 40 per cent of each weight. Less weight 20 per cent was assigned to the sub-index of skills, as it is based on proxy indicators.

B. *Simulation results*

The complete evaluation was conducted using the integrated method determined in Section III. The access, usage and skills sub-index weights, IDI sub-indexes weights of global regions, and the proposed method weight indices are listed in Table 2.

Table 2. Weights of IDI indicators in sub-indexes and Weights of IDI sub-indexes

Region, number of countries	**Africa, 38**	**Americas, 35**	**Arab states, 19**	**Asia Pacific, 34**	**CIS, 10**	**Europe, 40**	**W_{iesc}**
				Access sub-index			
A1	0.170	0.207	0.174	0.214	0.255	0.166	0.1886
A2	0.225	0.145	0.195	0.210	0.143	0.140	0.1977
A5	0.121	0.184	0.194	0.077	0.171	0.129	0.1613
HH4	0.237	0.233	0.219	0.246	0.256	0.283	0.2280
HH6	0.247	0.231	0.218	0.254	0.175	0.281	0.2244
				Usage sub-index			
HH7	0.429	0.397	0.367	0.366	0.349	0.364	0.3681
A3	0.219	0.250	0.305	0.307	0.323	0.340	0.3060
A4	0.353	0.353	0.327	0.326	0.328	0.297	0.3259
				Skills sub-index			
S1	0.318	0.338	0.348	0.341	0.327	0.279	0.3281
S2	0.356	0.347	0.349	0.346	0.373	0.391	0.3493
S3	0.326	0.315	0.303	0.313	0.299	0.330	0.3225
			IDI index				
Access *sub-index*	0.455	0.461	0.435	0.488	0.459	0.460	0.4404
Usage *sub-index*	0.265	0.249	0.263	0.263	0.255	0.253	0.2621
Skills *sub-index*	0.280	0.290	0.302	0.249	0.286	0.287	0.2975

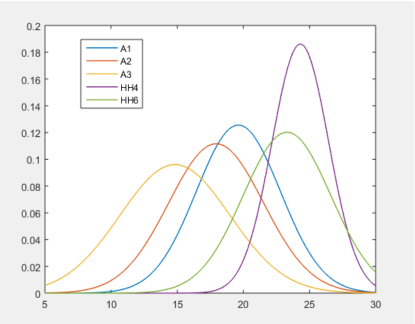

Fig. 1. Access sub-index indicators normal distribution curve

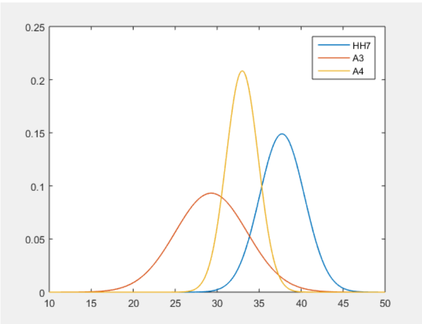

Fig. 2. Use sub-index indicators normal distribution curve

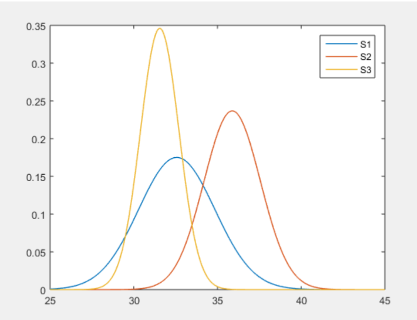

Fig. 3. Skill sub-index indicators normal distribution curve

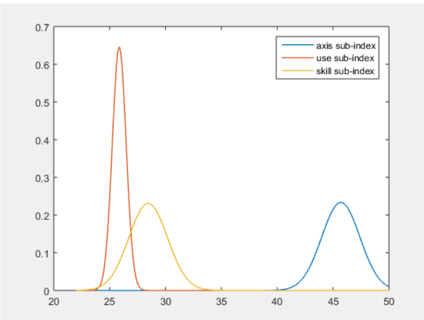

Fig. 4. IDI sub-indexes distribution

With the each sub-indexes there are access sub index covering A1, A2,A5, HH4,HH6 ICT indicators, usage sub-index covering HH7,A3,A4 ICT indicators and skills sub-index covering mean years of schooling rate (S1), Secondary gross enrolment ratio (S2), tertiary gross enrolment ratio (S3) we get the a new decision matrix. Table1 shows the difference percentages weights of IDI sub-indexes between ITU methodology of IDI and proposed method by each indicator and sub-indexes. Weights of the indicators are chosen based on the study results of the main components. The indicator weight differences are shown on Table 1. The differences are the following: - Access sub-index (0.23-3.87) %, - Usage sub-index (0.74-3.48) %, - Skills sub-index (0.52-1.6) %. Based on the differences, IDI sub-indexes value from 4.04% to 13.79%.Therefore, IDI indicators weights and reference value need define. Analysis of the ICT indicator weights on IDI used show that the indicators mean weight with a 95% confidence level by eq. (15) and normal distribution chats of sub-indexes and of IDI are shown in Fig.1-4 and Table 1.

$$\begin{aligned} w_{\min} &= mean - z_{0.025} \cdot std.error\ of\ mean \\ w_{\max} &= mean + z_{0.025} \cdot std.error\ of\ mean \end{aligned} \qquad \text{eq. (15)}$$

The indicators 95% confidence level carried the percent value of 11.75 to 25.9 for the access sub-index, of 26.11 to 39.7 for the use sub-index, of 30.7 to 37.13 for the skill sub-index. Fig.4 shows distribution of sub-indexes in IDI. Weight values of sub-indexes with a 95% confidence level are shown in Fig.4. Fig.1-4 and Table 1-2 are clearly shown that the weights of IDI indicators which were defined by proposed method and mean weight with a 95% confidence level are different from the weights in ITU methodology. The weighted analysis, in the survey, for example, presents the weight coefficient of ICT indicators in IDI and sub-indexes.

V. CONCLUSION AND FUTURE WORK

The results showed that our proposed integrated entropy weighting method performs better with the traditional statistical metric. In this paper an index evaluation approach for weighting of IDI indicators by countries is proposed. The methodology (see III.A-D) we proposed in this paper can be used regardless of the changing number of ICT indicators in the sub-indexes (access, usage, and skills).

The proposed method provides a selection of weight entropy for IDI any ICT indicators. The integrated entropy weighting method has a significant impact to determine weights indicator inside sub-index and sub-indexes in IDI.

We have used that proposed method to define an entropy and correlation coefficient weights of IDI of ICT indicators.

It is an alternative route to combine a variety of mature methods to get an integrated method. It is beneficial to assimilate the advantages of each method and reduce shortcomings.

Furthermore, the weighting of metrics is a good way to exploit the integrated method of the model characteristics and ranking. The weighted analysis, in the survey, for example, presents the weight coefficient of ICT indicators in IDI and sub-indexes. We assume the approach proposed in the paper is helpful for weight decision in IDI indicators. Besides, ICT development rankings of global, regional, country, and inside counties can be listed.

The integrated entropy weighting method, which is our proposed index evaluation approach, can provide significant indicators to solve any range of ICT issues.

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BIOGRAPHY

Narantuya Erkhembaatar graduated with a bachelor in telecommunication engineer from the Polytechnic Institute of Mongolia in 1989 and in 2002 completed a master's degree in technology at Andhra University in India. Bachelor degree thesis: "The study of electronic exchange in telecommunication network of Ulaanbaatar city". Master degree thesis: "Development of CBT on Satellite communication". Research topic for PhD degree is in information theory and distribution of information potential.

Otgonbayar Bataa, in 1978 graduated from the Polytechnic Institute of Mongolia majoring in Radio communication engineer. Bachelor degree thesis: "Feasibility study of improving the efficiency of discrete information system". Master degree thesis (M.Sc) in 1995 "Some issues of speech synthesis". PhD degree thesis in 1996: "Study of Mongolian speech synthesis and applying it in telecommunication technics", in 2003, post Ph.D program thesis: "Optimal version of OFDM system frequency and time-distortion". Professor. Consulting engineer of Mongolia. Research topic: "Broadband, high speed integrated services technologies" (WiMAX, WiBro, Mobile IPTV, LTE etc).