Statistical Composite Indicator for Estimating the Degree of Information Society Development

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***Abstract* - The development of information and communication technologies and the rapid development of the IT sector have greatly contributed to the development of society in general. In recent years, the techniques for measuring the development of information and communication technologies have begun to rise. Subject of this study is to measure the development of the countries' ICT infrastructure, using statistical composite index. In order to measure the development, we will use composite IDI index, with special emphasis on the improvement of the index. In addition to the existing IDI method of ranking, we will use the I-distance. A comparative analysis of the created and the existing indexes shall be given.**

Keywords – Information and Communication Technology, Composite I-distance indicator, Information society development

I. Introduction

Twentieth century was marked by a number of technological innovations. Information and Communication Technology (ICT) has changed the way of life, learning, and work, and even larger transformation of the way that people, companies, and public institutions interact is expected in the future. Changes in all aspects of society by using ICT are developing the information society.

Every day the number of people that use information technology grows in the world. Developed countries use ICT to improve their socio - economic development, since it represents relevant productive and economic forces. Countries are constantly evaluating their positions and perspectives within ICT development [1], making an effort to progress, and aiming to build an inclusive information society [2, 3]. Certain authors introduced ICT indicator as highly important in determining countries' welfare [4].

Numerous institutions continuously monitor developments related to the increased use of technology and the Internet. Year 2013th was marked by significant numbers: 95% of world population uses mobile phones, 40% of world population uses Internet, etc. ICT is a basic structural part of modern society, and it has a wide social and economic impact. It plays an important role in strengthening economic growth and raising socio-economic development [5, 6]. Thus for example, IT literacy – the skill of handling information – is becoming crucial for individuals future success, while IT experts are infallible part of big business. IT literacy can be considered a 21st-century form of literacy [7]. In addition, ICT influences the industrial structure of regions and contributes to prosperity on many levels: productivity gains resulting from the development of ICTs, creating new business models and opportunities, creating better educational performance. These are the main reasons to examine the issue of measuring the counties' development rate from the informational perspective [8].

Recently, a group of authors made a study in order to measure information development, creating the ICT development index (IDI) [9]. It is a composite indicator that completely observes information society, and whose main purpose was to measure the level of ICT development, progress in ICT development, differences between countries with different levels of ICT development, and the development potential of ICTs.

Regarding the issue of composite indicators, each multi-criteria performance measurement is formed as one, and its stability ensures the amount of safety of the observed system. The importance of securing the safety of complex systems has been recognized by various risk analysts in industrial and nonindustrial sectors [10, 11, 12, 13, 14, 15, and 16]. The selection of an appropriate methodology is central to any attempt to capture and summarize the interactions among the individual indicators included in a composite indicator or ranking system [17, 18].

Paruolo, Saisana and Saltelli [19] consider that composite indicators aggregate individual variables with the aim to capture certain relevant, yet maybe latent, dimensions of reality. Composite indicators are often applied and constructed [20], and they have been adopted by a lot of institutions, both for specific purposes and for providing a measurement basis for the issues of interest. Saltelli et al. [21] characterize the issue of composite indicators as follows: "Composite indicators tend to sit between advocacy (when they are used to draw attention to an issue) and analysis (when they are used to capture complex multidimensional phenomena)." Results and values of composite indicators significantly depend on the indicator weights, and therefore are often the subject of controversy [23, 19].

There are common conclusions from different studies that multi-criteria methodology definitions suffer from a ranking instability syndrome [14, 23]; i.e. different researchers offer conflicting rankings as to what is "best". According to Keung, Kocaguneli and Menzies [14], given different historical datasets, different sets of best ranking methods exist under various different situations, which is also one of the important directives for our research.

This paper primarily proposes an improved methodology of measuring the information society development. Instead of subjectively assigned weights, basic idea is to statistically measure the weights for each indicator that IDI consists of. This paper will be organized as follows: in Section 2 a review of IDI methodology is given. Section 3 describes the basic concepts of our proposed methodology, and section 4 presents the results. In the final chapter concluding remarks are given.

II. IDI INDEX

The ICT Development Index (IDI) is a tool used to monitor information society development and the development potential of ICTs, which combines 11 indicators related to ICT Access, Use and Skills into a single composite index [9]:

- *ICT Access* reflects the level of network infrastructure and access to ICTs, capturing its readiness. It includes five infrastructure and access indicators: fixed telephony, mobile telephony, international Internet bandwidth, households with computers, and households with Internet access.
- *ICT Use* reflects the level of use of ICTs in society, capturing its intensity. It includes three ICT intensity and usage indicators: Internet users, fixed broadband, and mobile broadband.
- *ICT Skills* reflects the result/outcome of efficient and effective ICT use, capturing its capability or skills as indispensable input indicators. It includes three proxy indicators: adult literacy, gross secondary and tertiary enrolment.

The main data source used in this study is a set of the 11 aforementioned IDI indicators, of which the first five refer to ICT Access, the next three to ICT Use, and the last three represent ICT Skills. These indicators are [9]:

- *Fixed Telephone Lines per 100 Inhabitants* – Telephone lines connecting a subscriber's terminal equipment to the public switched telephone network (PSTN) and which have a dedicated port on a telephone exchange, though this may not be the same as an access line or a subscriber. The number of ISDN channels and fixed wireless subscribers are included in this indicator.
- *Mobile Cellular Telephone Subscriptions per 100 Inhabitants* – The number of subscriptions to a public mobile telephone service using cellular technology, which provides access to the Public Switched Telephone Network (PSTN). While post-paid and prepaid subscriptions are included in this indicator, it does not differentiate between subscriptions and subscriber (person). Therein, as one subscriber may have multiple subscriptions, it would be useful to distinguish further between the number of mobile subscriptions and the number of individuals using a mobile phone.
- *International Internet Bandwidth (bit/s) per Internet User* – The capacity that backbone operators provide to carry Internet traffic. This is measured in bits per second per Internet user.
- *The Proportion of Households with a Computer* – A computer refers to a desktop or laptop computer. This does not include equipment that may have some embedded computing abilities, such as mobile cellular phones, personal digital assistants or TV sets.
- *The Proportion of Households with Internet Access at Home* – not assumed to be only via a computer. This may also be by mobile phone, game console, digital TV, etc... Access can be via a fixed or mobile network.
- *Internet Users per 100 Inhabitants* – The increasing use of the Internet through mobile devices is not necessarily reflected in these estimates.
- *Fixed Broadband Internet Subscribers per 100 Inhabitants* – Subscribers to paid, high-speed access to the public Internet (over a TCP/IP connection). Subscribers with access to data communications (including the Internet) via mobile cellular networks are excluded in this indicator.
- *Mobile Broadband Subscriptions per 100 Inhabitants* – Subscriptions to mobile cellular networks with access to data communications at broadband speeds, irrespective of the device used to access the Internet (handheld computer, laptop, or mobile cellular telephone). These services are typically referred to as "3G" or "3.5G".
- *Adult Literacy Rate* – The percentage of the population aged 15 years and over who can both read and write, as well as understand a short simple statement regarding his/her everyday life.
- *Gross Enrolment Ratio (Secondary and Tertiary Level)* – the total enrolment in a specific level of education, regardless of age, expressed as a percentage of the eligible official school-age population that corresponds to the same level of education in a given school-year.

The IDI index methodology has predefined the pattern for measuring a country's ICT structure, which includes ICT Access and ICT Use at 40% and ICT Skills at 20%. The detailed weights are given in Table 1.

III. PROPOSED METHODOLOGY

A. I-distance method

The common case with different ranking methods is that their bias and subjectivity can affect the measurements and evaluation. This problem can

TABLE I.
IDI INDEX INDICATORS AND THEIR WEIGHTS

Category	Indicators	%	weights
ICT access	Fixed Telephone Lines per 100 Inhabitants	20	40%
	Mobile Cellular Telephone Subscriptions per 100 Inhabitants	20	
	International Internet Bandwidth (bit/s) per Internet User	20	
	The Proportion of Households with a Computer	20	
	The Proportion of Households with Internet Access	20	
ICT use	Internet Users per 100 Inhabitants	33	40%
	Fixed Broadband Internet Subscribers per 100 Inhabitants	33	
	Mobile Broadband Subscriptions per 100 Inhabitants	33	
ICT skills	Adult Literacy Rate	33	20%
	Secondary Gross Enrolment Ratio	33	
	Tertiary Gross Enrolment Ratio	33	

somewhat be surpassed using the I-distance method, a metric distance in an n-dimensional space, which has recently made a significant breakthrough [24, 25, 26, 27, 28]. It was originally defined by professor Branislav Ivanovic [29, 30], who devised this method to rank countries according to their level of development based on several indicators, where the main issue was how to use all of them in order to calculate a single synthetic indicator, which will thereafter represent the rank.

For a selected set of variables X^T=() $X^T = (X_1, X_2, \ldots X_k)$ chosen to characterize the entities, the I-distance between the two entities $e_r = (x_{1r}, x_{2r}, \ldots x_{kr})$ and $e_s = (x_{1s}, x_{2s}, \ldots x_{ks})$ is defined as

$$D(r,s) = \sum_{i=1}^{k} \frac{|d_i(r,s)|}{\sigma_i} \prod_{j=1}^{i-1} \left(1 - r_{ji.12\ldots j-1}\right) \quad (1)$$

where $d_i(r,s)$ is the distance between the values of variable X_i for e_r and e_s, e.g. the discriminate effect,

$$d_i(r,s) = x_{ip} - x_{is} \quad i \in \{1, \ldots k\} \quad (2)$$

σ_i the standard deviation of X_i, and $r_{ji.12..j-1}$ is a partial coefficient of the correlation between X_i and X_j, (j<i) [29, 31].

In order to surpass the problem of negative coefficient of partial correlation, which can occur when it is not possible to achieve the same sign mark for all variables in all sets, it is suitable to use the square I-distance. It is given as:

$$D^2(r,s) = \sum_{i=1}^{k} \frac{d_i^2(r,s)}{\sigma_i^2} \prod_{j=1}^{i-1} \left(1 - r_{ji.12\ldots j-1}^2\right) \quad (3)$$

The I-distance measurement is based on calculating the mutual distances between the entities being processed, whereupon they are compared to one another, so as to create a rank. It is necessary to fix one entity as a referent in the observing set using the I-distance methodology. The ranking of entities in the set is based on the calculated distance from the referent entity.

B. Composite I-distance indicator methodology

In order to create more stable ranking methodology we have modified the weights given by the original methodology. The process of establishing adequate weights shall be described in detail. Proposed methodology is referred to as *Composite I-distance indicator (CIDI) methodology*.

The study includes the analysis and data collection of the composite IDI index and ranks of the countries for 2008, 2010, 2011 and 2012, as well as search for new indexes to improve the existing one. As mentioned before, the current structure of the composite indicator is used since 2008. Yet, the development of ICT is a continuous process, so the composite index must constantly be improved.

For each year we have calculated I-distance values, and created I-distance ranks. Subsequently, we have examined the stability for each of the compounding indicators, by calculating the Pearson correlations between the I-distance results and input indicators.

The main reason for using Pearson correlations between the I-distance results and input indicators in this methodology is the special feature of I-distance method: it is able to present the relevance of input indicators. Instead of defining subjective weights to input indicators, as it is done within the IDI index, I-distance method defines which of the input indicators are most important for ranking process, by putting them into a specific order of importance according to these correlations.

Next step in the proposed methodology, was calculating the new weights for each of the compounding indicators, which are based on the appropriate Pearson correlations. Weights are formed by weighting the empirical Pearson correlations: values of correlations are divided with sum of correlations. The final sum equals 1, thus forming the novel appropriate weighting system:

$$w_i = \frac{r_i}{\sum_{i=1}^{k} r_i} \quad (4)$$

where r_i is a Pearson correlation between *i*-th input variable and I-distance value.

Final weights represent the means of acquired values. This is one of the significant contributions of our paper, because instead of subjectively defining the values of weights, our principle is based on methodological and statistical concept, defined by I-distance method. This way we are able to significantly improve IDI methodology and propose a novel improved composite I-distance indicator, which would measure the information society development. The proposed weights and the ranking results are given in the results section.

IV. RESULTS

First step in our research implies calculating I-distance values for IDI index, for each year from 2008 to 2012. The inputs in calculating I-distance values are eleven indicators (see Table 1) which constitute IDI index. The relevance of I-distance ranking is presented and elaborated in number of scientific papers [23, 26, 27, and 28]. Thus, we were able to gain I-distance values for four consecutive years. Subsequently, we have calculated the correlations between I-distance values and the whole set of input indicators [26, 27] for all referred years.

Since the results have shown to be quite stable, and there were no large oscillations between the correlations, we have calculated the new weights for each compounding indicator which are based on the appropriate correlations of these items. The proposed weights are calculated by dividing the appropriate correlations with the sum of correlations, providing the sum to equals 1 (see Section 3). Thus we have obtained the appropriate weights for input indicators. Weights for years 2008, 2010, 2011 and 2012, with mean values and standard deviations are presented in Table 2.

TABLE II.
WEIGHTINGS OF IDI INDICATORS BASED ON I-DISTANCE METHODOLOGY

		CIDI weights						IDI weights	
Category	Indicators	2008	2010	2011	2012	**mean weights**		weights	
ICT access	Fixed Telephone Lines per 100 Inhabitants	0.106	0.110	0.098	0.092	0.101	0.502	0.08	0.4
	Mobile Cellular Telephone Subscriptions per 100 Inhabitants	0.086	0.082	0.088	0.080	0.084		0.08	
	International Internet Bandwidth (bit/s) per Internet User	0.127	0.104	0.122	0.126	0.120		0.08	
	The Proportion of Households with a Computer	0.097	0.100	0.094	0.099	0.098		0.08	
	The Proportion of Households with Internet Access	0.099	0.101	0.096	0.101	0.099		0.08	
ICT use	Internet Users per 100 Inhabitants	0.097	0.100	0.091	0.096	0.096	0.27	0.133	0.4
	Fixed Broadband Internet Subscribers per 100 Inhabitants	0.084	0.082	0.100	0.097	0.091		0.133	
	Mobile Broadband Subscriptions per 100 Inhabitants	0.071	0.074	0.089	0.096	0.083		0.133	
ICT skills	Adult Literacy Rate	0.072	0.079	0.072	0.073	0.074	0.228	0.067	0.2
	Secondary Gross Enrolment Ratio	0.077	0.081	0.071	0.077	0.076		0.067	
	Tertiary Gross Enrolment Ratio	0.083	0.086	0.079	0.064	0.078		0.067	

Proposed weights are mean values of weights calculated for period from 2008 to 2012. Table 2 also presents the differences in weights proposed by IDI index and I-distance weights.

If we examine Table 2, we can notice significant aberrations from the officially defined weights. The IDI methodology have given the highest weights to the group of indexes for ICT use, while, compared to it, the I-distance method gave slightly higher weights to ICT access. We have calculated the weights of indicators each year using the I-distance method. To some extent, I-distance weights deviate from their means, but when the given mean of the weights obtained by the I-distance method is compared to the official IDI weights, they are greater than or approximately equal for each indicator.

The largest differences are with indicators *Mobile Broadband Subscriptions per 100 Inhabitants*, *Fixed Broadband Internet Subscribers per 100 Inhabitants*, *International Internet Bandwidth (bit/s) per Internet User*, and *Internet Users per 100 Inhabitants*. *International Internet Bandwidth (bit/s) per Internet User* is weighted 8% according to the official IDI index, while our method calculates the share of this indicator to be 12%, giving it a larger weight. *Mobile Broadband Subscriptions per 100 Inhabitants*, *Fixed Broadband Internet Subscribers per 100 Inhabitants*, and *Internet Users per 100 Inhabitants* are weighted 13.3% according to the official IDI index, while our method calculates their shares to be smaller (about 9%), thus lowering its significance. Other values are more-less consistent with official IDI weights, showing our proposed method to be meaningful and profound.

On the ground of these matters, Table 3 presents the results of our research, giving the composite I-distance indicator scores, composite I-distance indicator ranks, as well as the comparison of our scores and official IDI index scores. The results are shown for 30 firstly ranked countries, 10 lastly ranked countries, as well as for Serbia and its neighboring countries, such as Croatia, Hungary, etc. The whole set of the results, for 156 countries, is available upon request.

As can be noted from Table 3, there are a lot of similarities between IDI scores and CIDI scores. This is due to the fact that weights that we have gained using our methodology are quite correspondent to official IDI index, yet somewhat different because they are based on the correlations between input indicators and I-distance values. These differences, shown in Table 2, cause some differences in ranks, which can also be seen in Table 3.

In order to assess the composite I-distance indicator, a Pearson correlation coefficient between the composite I-distance indicator scores and IDI index has also been calculated. Such correlation is significant at a 0.001 level ($p < 0.001$), and very strong, $r = 0.998$. The fact that our indicator correlates so closely with the IDI index, proves that it is equally suitable and greatly connected to the subject of interest. This validates the composite I-distance indicator as an acceptable measurement for evaluating information society development. As for the compared rankings gained by the two methods, a Spearman’s rho statistic has additionally been calculated. The correlation is also significant with $r_s = 0.999$, $p < 0.001$.

As mentioned before, our principle provides the methodologically and statistically justified weights, which are derived from the correlations calculated for 2008, 2010, 2011, and 2012. In addition, this method provides a different perspective on the importance of each input variable, and a correction in the weighting factor for each of the eleven input indicators. Moreover, not only our methodology gives more accurate result, but it is also more stable than the official IDI index. If we calculate the weights using the I-distance method and according to the composite I-distance indicator methodology, we are able to gain more stable results and to decrease the entropy of the ranking system.

V. CONCLUSION

The results have shown that the approach to measuring information society development using I-distance method is very important. I-distance uses the same basic indicators, but classifies them according to significance, thus creating composite I-distance indicator (CIDI). This

TABLE III.
CIDI SCORES, CIDI RANKS, AND ITS COMPARISON WITH OFFICIAL IDI SCORES AND RANKS

Country	CIDI score	CIDI rank	IDI score	IDI rank
Korea	8.748	1	8.57	1
Iceland	8.678	2	8.36	3
Denmark	8.568	3	8.35	4
Sweden	8.530	4	8.45	2
Hong Kong	8.456	5	7.92	10
Netherlands	8.365	6	8	7
Finland	8.357	7	8.24	5
Luxembourg	8.318	8	7.93	9
Norway	8.260	9	8.13	6
Australia	8.260	10	7.9	11
United Kingdom	8.234	11	7.53	16
Switzerland	8.124	12	7.78	13
Japan	8.007	13	7.82	12
New Zealand	7.996	14	7.64	15
Singapore	7.961	15	7.65	14
France	7.932	16	7.53	17
Germany	7.867	17	7.46	18
United States	7.717	18	7.98	8
Canada	7.687	19	7.38	19
Ireland	7.674	20	7.25	22
Austria	7.655	21	7.36	20
Belgium	7.606	22	7.16	24
Malta	7.586	23	7.25	23
Estonia	7.454	24	7.28	21
Spain	7.434	25	6.89	26
Israel	7.412	26	7.11	25
Slovenia	7.184	27	6.76	27
Barbados	7.074	28	6.65	28
Italy	6.922	29	6.57	29
Greece	6.914	30	6.45	31
…				
Croatia	6.606	37	6.31	37
…				
Russian Federation	6.530	40	6.19	39
Hungary	6.467	41	6.1	41
…				
Romania	5.820	52	5.35	54
…				
Serbia	5.758	54	5.34	55
…				
TFYR Macedonia	5.550	57	5.19	56
…				
Turkey	5.108	67	4.64	68
Bosnia and Herzegovina	5.080	68	4.71	66
…				
Mozambique	1.599	147	1.31	147
Ethiopia	1.578	148	1.24	150
Madagascar	1.566	149	1.28	148
Guinea	1.547	150	1.23	151
Eritrea	1.505	151	1.2	152
Guinea-Bissau	1.484	152	1.26	149
Burkina Faso	1.464	153	1.18	153
Niger	1.280	154	0.99	156
Chad	1.255	155	1.01	154
Central African Rep.	1.222	156	1	155

paper briefly presented the results of a research that introduces a new perspective on the measurement of countries' information development and compares it with the already familiar ICT development index (IDI). Like IDI, CIDI used the same eleven indicators related to the three ICT categories: Access, Use and Skills. Yet unlike the IDI, it assigns different weights to those indicators.

The important preference of our methodology is its correspondence to official IDI index. The results of the scores ($r=0.998$, $p<0.001$) as well as the results of ranks ($r_s=0.999$, $p<0.001$) are in an intense agreement. Thereunder, the weights that are assigned to appropriate indicators are quite similar (Table 2). These facts ensure the recognition and acknowledgement of our proposed method. Yet our methodology offers significant improvements and updating.

First important improvement is reflected in the objectiveness of our methodology. By defining the methodology of CIDI, we have overcome the disadvantage of subjectively assigned weights to the set of input indicators. Instead of using the bias weights, we have established the weighting system based on a multivariate statistical and methodologically grounded course. Furthermore, the weighting system that we have proposed in forming the CIDI is far more stable, producing a high degree of confidence.

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