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Composite Indicator of the Organisational Information and Communication Technologies Infrastructure—A Novel Statistical Index Tool

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Abstract: This paper proposes a tool for objective evaluation of organisations' information and communication technologies (ICT) infrastructure development level: Composite Indicator of the Organisational Information and Communication Infrastructure—CIOICTI. Based on separate research in 68 different companies, it aggregates hardware, software and humanware aspects of ICT development in organisations, especially valuing companies with synergetic aspects. It consists of six linear and non-linear indicator components, each designed to evaluate one specific aspect of ICT development, based on the weighted sum principle. The proposed CIOICTI examines ICT infrastructure as a necessary but not sufficient condition for successful ICT usage in business performance improvement. The obtained CIOICTI values are summarised in the distribution and tested for normality. Results are tested on the data from observed companies, averaged according to company size and industry and benchmarked. The proposed composite indicator can be used as an objective tool for researchers and practitioners to assess the level of ICT development for benchmarking with other companies, planning organisational changes or assessing infrastructural requirements for planning and implementation of ICT related projects in a business organisation.

Keywords: ICT (information and communication technology); ICT development; ICT measurement; ICT management; composite indicator; benchmarking

MSC: 91B82; 90B50; 94A99

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1. Introduction

Information and communication technologies (ICT) have fuelled organisations' rapid development, especially during the last four decades, influencing the economy and business. At first, a positive influence on the economy and business was doubted, which created a well-known "productivity paradox" [1]. However, the researchers ensured a positive impact of ICT on

- Productivity: Khan and Santos (2002), [2] Draca et al. (2006) [3], Belorgey et al. (2006) [4], Jalava and Pohjola (2007) [5], Alshubir et al. (2019) [6], Hawash and Lang (2020) [7];
- Efficiency: Shao and Lin (2002) [8], Bechetti et al. (2003) [9], Chang and Gurbaxani (2012) [10], Lecerf and Omrani (2020) [11];
- Agility: Deghani and Navimipur (2019) [12];
- Overall firm performance Turedi and Zhu (2012) [13], Yu et al. (2021) [14], Del Gaudio et al. (2021) [15].

An ICT basis is required for the trending digital transformation [16], so organisations have more and more pressure to develop and manage necessary ICT infrastructure.

Researchers have investigated the tools for objective assessment of ICT infrastructure and adoption: Moore and Benbasat (1991) [17], Edberg (1997) [18], Cragg (2002) [19], Griffiths and McCord (2002) [20], Caldeira and Ward (2003) [21], Bayo-Moriones et al. (2005) [22], Kauffman and Kumar 2005 [23], El-Mashaleh 2007 [24], Ma et al., 2008 [25], Hanafizadeh et al., 2009 [26], Howard et al., 2009 [27], Malisuwan et al., 2015 [28], Afshar Ali et al., 2020 [29]) and its influence on organisation (Yang et al., 2007 [30], Cudanov et al., 2010 [31], Cudanov and Jasko 2012 [32], Miyazaki et al., 2012 [33]). A necessary but not sufficient precondition for developing ICT is its adoption and usage. In this study, the term "ICT development" refers to establishing prerequisite ICT infrastructure in an organisation: hardware, software and humanware. In such a definition, ICT development describes the potential for usage, and it is a required but not sufficient condition for actual usage of ICT by employees which depends on other, less tangible factors.

The development of measurement methods is one of the crucial guidelines of modern science, illustrated by a quote dubiously attributed to Galileo Galilee [34] (but still inherently valuable): "Measure what is measurable, and make measurable what is not so". This is especially important for management science because "you can't control what you can't measure" [35].

The Composite Indicator of Organisational ICT Infrastructure (CIOICTI)—an objective measurement tool of a complex construct such as corporate ICT infrastructure—proposed in this paper is needed to improve ICT management in organisations. It was developed by following the guideline that the only way to learn how to measure is to measure [35]. The proposed composite tool aggregates several indicators, each one describing a separate aspect of the observed phenomenon. Composite indicators and indices are widely used in the business environment [36–41]

CIOICTI is developed on the basis of the old Composite Index of ICT Adoption (CIICT) [31]. The CIICT was successfully used in the studies that compared levels of ICT adoption concerning dominant management styles [42], organisation size [31] and dominant management orientation [32]. Bolek et al. (2012) [43] utilised the concept while proposing the ICT advancement index. Applying the old CIICT formula in the corporate environment, we found that the term "infrastructure" describes measured phenomenon better than "adoption" which can be connected with the behavioural aspects of the ICT usage.

In order to build the proposed composite indicator, we selected several indicator components covering hardware, software and humanware, each component designed to evaluate one specific aspect of ICT development. Some of the components were already used in previous research to construct the CIICT [42]. The indicators were reconstructed to increase usability and functionality, as the selected components are aggregated using both linear and geometrical aggregation methods, ensuring that the composite measure meets the requirements. Explicit factor weighting is used to control the influence of individual components on the final composite value. We tested the proposed CIOICTI in 68 different companies. The results show that the highest average level of ICT adoption is achieved in large companies and within companies from the ICT and service sector. Further, the obtained CIOICTI values are summarised into a distribution indicating potential normality. Shapiro–Wilk and Kolmogorov–Smirnov tests suggest accepting the null hypothesis, proving that the CIOICTI values are normally distributed. This result is concurrent with the well-known theory of diffusion of innovation.

The paper is organised as follows. In Section 2, we present methods by describing indicator components and how they are aggregated in a composite formula. In Section 3, we present data used in our research and the obtained results. Moreover, we test the normality of the resulting distribution in order to relate the obtained results with the famous theory of diffusion of innovation. At the end of this section, we discuss the main limitations of the proposed indicator formula. Finally, Section 4 concludes the paper.

2. Mathematical Background

2.1. Aggregation Functions

Aggregation is the process of combining several numerical values into a single representative one, and the numerical function performing this process is called an aggregation function [44]. Aggregation functions [44,45] are functions that take real arguments from the closed interval [0, 1] and produce a real value in [0, 1]:

$$Agg : [0,\ 1]^n \rightarrow\ [0,\ 1] \tag{1}$$

where n represents number of aggregated components.

Four main classes of aggregation functions include [46]:

1. Averaging aggregation. It is the most common way to aggregate arguments in statistical analysis and decision making. The basic property of averaging is that the aggregated value cannot be above the highest arguments nor below the lowest argument:

$$min(x_1, x_2, \ldots, x_n) \le Agg(x_1, x_2, \ldots, x_n) \le max(x_1, x_2, \ldots, x_n) \tag{2}$$

Most commonly used aggregation functions of this types are the arithmetic mean:

$$Agg(x_1, x_2, \ldots, x_n) = \frac{1}{n} max(x_1, x_2, \ldots, x_n) \tag{3}$$

and the geometric mean:

$$Agg(x_1, x_2, \ldots, x_n) = \sqrt[n]{x_1 x_2 \ldots x_n} \tag{4}$$

2. Conjunctive aggregation. The basic property of this class of functions is:

$$Agg(x_1, x_2, \ldots, x_n) \le min(x_1, x_2, \ldots, x_n) \tag{5}$$

Most commonly used aggregation functions within the class are the minimum:

$$Agg(x_1, x_2, \ldots, x_n) = min(x_1, x_2, \ldots, x_n) \tag{6}$$

and ordinary product:

$$Agg(x_1, x_2, \ldots, x_n) = x_1 x_2 \ldots x_n \tag{7}$$

3. Disjunctive aggregation has the property:

$$max(x_1, x_2, \ldots, x_n) \le Agg(x_1, x_2, \ldots, x_n) \tag{8}$$

The most commonly used aggregation function of this class is the maximum:

$$Agg(x_1, x_2, \ldots, x_n) = max(x_1, x_2, \ldots, x_n) \tag{9}$$

4. Mixed aggregation is used if it does not belong to any of the previous classes.

2.2. Arithmetic Average vs. Product Aggregation

In this section, we compare two aggregation functions of interest for this paper: the weighted arithmetic mean and ordinary product. The latter belongs to the class of conjunctive aggregation functions, and, as its name implies, it models conjunction (logical AND). As such, the product function will not allow for compensation of arguments—low scores of some arguments cannot be compensated by other scores. The arithmetic average is the opposite case; it is good for aggregating arguments that can be added together and allows their compensation. Further, the weighted arithmetic mean represents the linear interpolation of arguments, while the product function has nonlinear properties.

3. Composite Indicator of Organisational ICT Infrastructure Development Methods

Developing high-quality ICT infrastructure in an organisation requires caring for the following synergetic aspects: hardware, software and humanware. Consequently, building a measurement tool to measure ICT development in an organisation requires the same. In this study, the term "ICT development" refers to establishing a prerequisite ICT infrastructure considering all three aspects mentioned above. Therefore, we propose a composite indicator to aggregate these aspects into a single estimate suitable for benchmarking with other organisations to measure the observed phenomenon.

The proposed CIOICTI is intended to satisfy the following demands:

- To consider various factors of the ICT development in the organisation described in the literature and observed throughout the practical experience.
- To maximise the practical usability of the formula for other consultants and researchers. Therefore, it consists of data that can be easily collected during interviews within a company. According to Einstein's recommendation, it should be "as simple as possible but not simpler". However, simplification should not be insisted on if it diminishes the power of accurate description.
- To be as objective as possible, because of the perceived tendency of different companies where individuals have different subjective assessment criteria.
- The proposed indicator should be scalable with a predefined value range. This will ensure its ease of use as a tool for managing ICT development in organisations, benchmarking it with other organisations and comparing it with other organisational traits.

3.1. Organisational ICT Infrastructure Indicators

The proposed Composite Indicator of Organisational ICT infrastructure (CIOICTI) is developed from the older Composite Index of ICT Adoption (CIICT) [42], and therefore it is meant to be an upgrade compared to its predecessor. This means we used the old CIICT component structure as the starting point to build the CIOICTI: five indicators to measure specific aspects of ICT infrastructure and one product component to capture synergetic ICT effects within organisation. A decade-long experience in ICT-related projects proved the concept of the CIICT but also gave us an opportunity to identify potentials for improvement. These improvements led us to the main prerequisites for establishing high-quality ICT infrastructure in an organisation. These prerequisites include necessary ICT equipment, a highly developed internal network, high coverage of the work operations with the ICT, the integrated database and the existence of necessary ICT support. In order to estimate the ICT development level in an organisation, one needs to assess the level of development of each one of the previously mentioned prerequisites. To achieve this, we used several individual indicators, each one to estimate one the aspects mentioned above. Following the composite indicator creation guidelines [47,48], we aggregated the selected indicators into a new composite formula to measure ICT development in an organisation. This tool can be helpful to decision makers in managing ICT development in a business organisation.

The first step in constructing a composite indicator was to look for the components—individual indicators used to build a composite measure. As mentioned, we started from the known set of ICT adoption indicators used to create the CIICT and used our consulting experience to improve indicators to measure the quality of the organisational ICT infrastructure.

To estimate the necessary ICT equipment level in a business organisation, we used a simple but effective indicator called "Number of computers per employees" (NCE). It is calculated as the following ratio:

$$NCE = \frac{NC}{NE} \tag{10}$$

where NC stands for the number of computers in an organisation, and NE represents the total number of full-time employees, both with limited and indeterminate employment contact. The same indicator was used by Cudanov et al. (2009) [42]. NCE is a straightforward but effective indicator that can be easily calculated, giving decision-makers hints about the basic ICT infrastructure in an organisation. In a wider sense, "computers" do not only need to be desktops/laptops but also tablets, handheld devices, etc.

Another important aspect of ICT infrastructure is to estimate the level of internal network development in organisations. A highly developed internal network speeds up the internal communication process, making the organisation more efficient. We use the indicator called "Internal network coverage":

$$INC = \frac{NCC}{NC} \tag{11}$$

where *NCC* represents the number of computers that are connected to the internal network in an organisation. Again, this indicator should be carefully assessed. While most computers in the corporate environment are technically connected to the internal network, using its benefits is not so common in the business organisation. Intranet services are neglected or used fragmentally, and this whole indicator can be weighted by the intensity of usage. For example, a bit extreme but possible case can be that 90% of computers are connected to the intranet but in average use only 20% of its functionalities. Researchers can weight the 90% with 20% usage and by multiplying obtain 18%, which is a more precise measurement than 90% for *INC* in this case.

Further, to estimate what part of the business activity is covered with the ICT, we use the indicator called "Average Coverage of Business Functions with ICT", calculated with

$$ACBF = \frac{1}{n}\sum_{i=1}^{n} CBF_i \tag{12}$$

where CBF_i stands for Coverage of *i*th business function with ICT representing the percentage of work within the business function *i* that is achieved with ICT support. We use the average rather than the simple sum, which was used by [42]. The main reason for that is the practical gathering of data, which can be biased if some business functions are missing or rudimentary, and it is illustrated with a simple example given in Table 1, showing the difference between the two approaches.

Table 1. Comparison between different approaches to calculate coverage of business operations by ICT.

Company	Coverage of Particular Business Functions' Operations with ICT								Sum (Old)	Average (New)
	HR	Acc.	Fin.	Tech.	Comm.	Leg.	Sec.	Admin.		
C_A	0.5	1	0.8	0.5	0.5	0.2	0	0.5	4.00	0.538
C_B	0.8	1	1	-	0.7	0	-	0.5	4.00	0.717
C_C	-	1	1	-	1	-	-	-	3.00	1.00

In the previous table, *HR* stands for the human resource function, *Acc.* for accounting, *Fin.* for financial function, *Tech.* for technical core, *Com.* for commercial function, *Leg.* for legal, *Sec.* for corporate security and Admin for administrative (overall management) function. If some of the mentioned functions are not present in the organisation (at least sufficiently to be a distinctive part of organisational structure), it is represented by the "-"sign, while the "0" means the function is present, but ICT does not cover its operations at all.

Gathering data from the companies in practice while using the old, simple sum approach to calculate the "Coverage", companies C_A and C_B emerge with the highest of business functions' operations ICT coverage. In the new approach, the average value shows a completely different situation, giving the company C_C's advantage, which has only three business functions differentiated in its organisational structure, but all three are completely covered with the ICT. The average function used in ACBF made this factor independent of the organisational structure, which was not the case in the old approach.

Another important aspect is database integration. It is a fundamental precondition for the full utilisation of the ICT and its positive effects on productivity. The highly integrated company database offers the fast and reliable exchange of data and information between business functions/units and additionally external stakeholders, fulfilling the goal of ICT infrastructure. It is useful in the implementation of ERP [49] and is observed in cloud-based ERP [50]. To measure database integration in a company, we use "Average integration of database":

$$AIDB = \frac{1}{n}\sum_{i=1}^{n} IDB_i \tag{13}$$

where IDB_i indicates integration of the local database (on the level of i^{th} business function) into the global company's database. IDB_i is a binary variable; $IDB_i = 1$ if the local database is integrated into the main organisation's database (the most usual case with integrated information systems such as ERP) and $IDB_i = 0$ if the local database is not integrated. The old CIICT formula used a binary variable to describe database integration as an answer to a simple Yes/No question: "Is your company's database integrated?". The binary variable was too rigid to describe possible situations in companies with partially integrated databases. The proposed indicator can make a better gradation among companies and describe more possible cases.

The final aspect of ICT infrastructure is humanware—a necessary ICT support as a precondition for effective use of the ICT in a company, as hardware and software are often underutilised without the necessary administration. We use a binary variable denoted as "ICT support" to describe the humanware aspect of ICT development. The proposed variable has a value equal to 1 if there is complete ICT support available in a company or equal to 0 if there is no such support. In medium and large companies, this ICT support is observed through the existence of special ICT/IT departments, while small companies have dedicated employees often called a "database administrator/engineer" or "system administrator/engineer". If the formula user estimates that subjective assessment of the value within the interval is better than binary objective assessment, with explanation, a value between 0 and 1 weighted by the quality and availability of that support can be given, e.g., 0.8. Following the logic of the common business system, future collection of ICT support data can gather information from the basic business functions/sectors on the proposed scale and then calculate the arithmetical average or use advanced methods such as AHP to aggregate the different responses. That provides much more precision and accuracy but needs significant resources to gather the data.

In the following Table 2, we present summary information on the indicator set used to create the composite measure. Each one of the indicators from the table estimates one specific aspect of ICT infrastructure.

Table 2. ICT infrastructure partial indicators and their description.

Indicator	*Abbreviation*	*ICT Infrastructure Aspect*	*Formula*
Number of Computers per Employee	NCE	Hardware	$NCE = \frac{NC}{NE}$
Internal Network Coverage	INC	Hardware	$INC = \frac{NCC}{NC}$
Average Coverage of Business Functions with ICT	ACBF	Software	$ACBF = \frac{1}{n}\sum_{i=1}^{n} CBF_i$ $CBF_i \in [0,\ 100\%]$
Average Integration of Database	AIDB	Software	$AIDB = \frac{1}{n}\sum_{i=1}^{n} IDB_i$ $IDB_i \in [0,\ 1]$
ICT support	ICTS	Humanware	$ICT \in [0,\ 1]$

3.2. CIOICTI Component Selection

The second step was to investigate correlations within the indicator set. This is important to avoid overweighting some aspects of ICT infrastructure within the composite indicator. In the following Table 3, we present correlations between ICT indicators.

Table 3. Correlations between ICT indicators.

		NCE	INC	ACBF	AIDB	ICTS
NCE	Corr.	1	0.352 **	0.183	0.173	0.150
	Sig.	-	0.003	0.134	0.159	0.222
INC	Corr.	0.352 **	1	0.321 **	0.428 **	0.233
	Sig.	0.003	-	0.008	0.000	0.056
ACBF	Corr.	0.183	0.321 **	1	0.215	0.275 *
	Sig.	0.134	0.008	-	0.079	0.023
AIDB	Corr.	0.173	0.428 **	0.215	1	0.340 **
	Sig.	0.159	0.000	0.079	-	0.005
ICTS	Corr.	0.150	0.233	0.275 *	0.340 **	1
	Sig.	0.222	0.056	0.023	0.005	-

** Correlation is significant at the 0.01 level (2-tailed). * Correlation is significant at the 0.05 level (2-tailed).

The correlation analysis points out that the second indicator (INC) is significantly correlated to all but one other indicator. As expected, the correlation is significantly high between NCE and INC, suggesting there is a redundancy in information they present. For this reason, we drop the INC indicator from selection and use the rest of the indicators to construct the composite measure. However, our recommendation is not strict if the future researchers present argumentation for the INC to be included, or if the practitioners accept the compromise of redundancy to include subtly different contributions of the intranet-connected computers, they can use the indicator form with the INC included.

3.3. Normalisation

Further, we normalised selected indicators in order to bring them to the same unit interval, to avoid "adding up apples and pears" [51]. There are numerous normalisation methods such as standardisation, re-scaling, ranking, etc. To select an adequate normalisation method, we investigated the basic statistical properties of the selected CIOICTI components, shown in Table 4.

Table 4. CIOICTI components and their value range.

CIICT Component	Number of Computers per Employee (NCE)	Average Coverage of Business Operations with ICT (ACBF)	Average Integration of Database (AIDB)	ICT Support (ICTS)
Min sample value	0.04	0.0 (0%)	0.0	0.0
Max sample value	2.2	1.0 (100%)	1.0	1.0
Min expected value	0.0	0.0 (0%)	0.0	0.0
Max expected value	3	1.0 (100%)	1.0	1.0

The value range analysis shows that all of the selected indicators except NCE are in the unit interval [0, 1]. While, in theory, there is no upper limit for the NCE, in practice, the employee is expected to use three computer devices at most—one desktop, one laptop and one handheld device. Extreme cases such as server farms are not considered since employees do not directly use server computers to perform business tasks—the company uses it as a raw computing resource power. Therefore, we need to apply some normalisation method to this component. The normalisation method should also take into account the objectives of the composite indicator besides the data properties [51]. For example, one should think about whether exceptional behaviour needs to be rewarded/penalised when the composite indicator is created.

The authors intend to develop a general rather than industry-oriented indicator, which can be used to compare companies from different industry sectors. Hence, there is a necessity for disabling discrimination in some industry sectors; positive discrimination of companies in the ICT-related industries—companies with high values of the NCE ratio (e.g., software engineering companies, computer training schools, banks, etc.) and negative discrimination of labour-intensive companies (those with low values of this ratio). To achieve this, we use specific transformation to trim the tail of the indicator distribution to avoid its extreme values and create a bigger gap in the index value between the ICT-oriented and labour-oriented companies. The proposed transformation is

$$NCE = \min\left(\frac{NC}{NE}, 1\right) \tag{14}$$

3.4. Aggregation and Weighting

The issue of aggregation of the information is the central one in the process of constructing a composite indicator. Different aggregation functions are possible (Section 2). Linear aggregation using the arithmetic mean implies full compensability, i.e., poor performance on some indicators can be compensated by sufficiently high values of other indicators [51]. On the other hand, nonlinear aggregation using the product function entails a partial compensability (i.e., compensability is lower when the composite indicator contains indicators with low values), rewarding those with higher scores. In this study, we use both linear and geometric approaches.

During our research, we built a version of the composite indicator using linear aggregation of the selected components, but it proved to be insufficient to describe the observed phenomenon. For example, consider a company with a high number of computers per employees and a high coverage of business functions' operations with the ICT, but a low-to-medium level of database integration. Our consulting experience has taught us that the level of ICT development in such a company should not necessarily be considered the highest. This gave us an idea that there exists some sort of nonlinearity that should be taken into consideration when measuring ICT infrastructure. For this reason, we assume that all individual factors (NCE, ACBF, AIDB and ICTS) have an even more significant influence on the level of ICT development if they all highly developed within a business organisation. This emphasises the importance of partial compensability. Many authors previously described a similar effect [42,52,53]

We model the composite indicator (CIOICTI) using two aggregation functions: the weighted arithmetic mean and product. The weighted aggregated mean is the most commonly used way to build composite indicators. We use it to enable full compensation while adding CIOICTI components together. To incorporate previously explained the nonlinear synergetic effect in ICT infrastructure development, we use the product function of individual components (indicators). The following is the proposed CIOICTI formula:

$$\begin{aligned} CIOICTI = 100\cdot\Bigg(& w_1\cdot\left(w_{11}\cdot min\left(\tfrac{NC}{NE},1\right) + w_{12}\cdot\left(\tfrac{1}{n}\sum_{j=1}^{n} CBF_j\right) + w_{13}\cdot\left(\tfrac{1}{n}\sum_{j=1}^{n} IDB_j\right) + w_{14}\cdot ICTS\right) \\ & + w_2\cdot\left(min\left(\tfrac{NC}{NE},1\right)\cdot\left(\tfrac{1}{n}\sum_{j=1}^{n} CBF_j\right)\cdot\left(\tfrac{1}{n}\sum_{j=1}^{n} IDB_j\right)\cdot ICTS\right)\Bigg) \end{aligned} \tag{15}$$

The first part of the CIOICTI is the weighted sum of the selected indicators—the common approach to create the composite indicator. The second part of the CIOICTI is the product of the selected components. It is aimed to reward those organisations that could create a synergetic effect having developed all elements of ICT infrastructure or to punish those organisations who lack some parts of ICT infrastructure. These two parts are weighted using w_1 and w_2. Further, within the first part of the composite index, individual indicators are weighted separately. Finally, the sum of two parts is multiplied by 100 since we projected the CIOICTI to be in the $[0,\ 100]$ value range.

The issue of aggregation comes together with the weighting. Weights are assigned to components to control their influence on the resulting composite value and reflect their significance (economic, statistical, etc.); thus, weighting models need to be made explicit and transparent [51]. Numerous weighting techniques are commonly used: factor analysis, analytical hierarchy process (AHP) and weighting based on experts' opinions.

Moreover, one should keep in mind that weights are essentially value judgments no matter which method is used; it must be used to indicate explicitly the objectives underlying the construction of a composite indicator [51,54]. In this study, we use an expert-based approach to assign weights according to our consulting experience and in accordance with the following objectives:

- Aggregate influence of individual components (first part of the CIOICTI) should be dominant, but at the same time the synergetic effect of ICT infrastructure (second part of the CIOICTI) should have a significant influence on the composite measure.
- Within the first part of the CIOICTI, individual indicators should be equally weighted to avoid overweighting some of the aspects (hardware, software and humanware) of the organisational ICT infrastructure.

Having these objectives in mind, and based on our consulting experience, we propose the weighting scheme in Table 5.

Table 5. The set of weights used in this research.

w_j	Weight Factor
w_1	0.60
w_{11}	0.25
w_{12}	0.25
w_{13}	0.25
w_{14}	0.25
w_2	0.40
Σ	1.00

3.5. The Final CIOICTI Formula

When the proposed weighting scheme is included, we obtain the final CIOICTI formula:

$$
\begin{aligned}
CIOICTI = {} & 15 \cdot \min\left(\frac{NC}{NE}, 1\right) + 15 \cdot \left(\frac{1}{n}\sum_{j=1}^{n} CBF_j\right) + 15 \cdot \left(\frac{1}{n}\sum_{j=1}^{n} IDB_j\right) + 15 \cdot \mathrm{ICTS} + 40 \\
& \cdot \min\left(\frac{NC}{NE}, 1\right)\left(\frac{1}{n}\sum_{j=1}^{n} CBF_j\right) \cdot \left(\frac{1}{n}\sum_{j=1}^{n} IDB_j\right) \cdot \mathrm{ICTS}
\end{aligned}
\tag{16}
$$

4. Results and Discussion

4.1. Data

The data used in this study are extracted from the broader research of 68 organisations in the transitional countries of Southeast Europe-Serbia and Montenegro. Sources of information were existing documents and reports, management interviews and employees' interviews. Data were gathered and updated up until January of 2020. For researchers interested to compare indicator values which will change due to the fast development of the ICT, it is important to note that our results cover a wider time range before the COVID-19 pandemic. Document sources cover strategies, human resources, technological, financial and all other important parameters of each organisation. The sample was balanced to represent the area in terms of equally distributed locations in major and minor cities, industry, financial success and number of employees. The sample covered many different industries, from consulting and software engineering to agricultural production (Table 6). The size of the companies in the sample ranged from 7 to 2894 employees.

Table 6. Distribution of companies concerning size and industry.

SIZE/INDUSTRY	Production	Commerce	ICT	Services	Total
Small	14	5	9	10	38
Medium	7	8	2	3	20
Large	7	1	0	2	10
Total	28	14	11	15	68

During data gathering, problems with estimated values or misunderstanding of questions by interviewing personnel emerged on several occasions. If estimations given by different personnel were perceivably different, researchers asked for clarification and a second estimation, common to the simplified application of the Delphi method used in De Incaza and Pick (1998) [55] and Radauceanu et al. (2008) [56]. Regarding the intangible nature of some indicators, attention was also directed towards discussions with managers, sometimes to ambiguous attitudes, messages and insinuations as guidelines for gathering data. Companies' written reports were used to detect inconsistencies in data, comparing qualitative with quantitative descriptions. Researchers explained questions with examples from different companies and calculated the arithmetical mean for given values if no unusual discrepancies were observed.

4.2. Results

This section presents the results of measuring ICT development in organisations from the data sample described in the previous section. The following Table 7 presents the results for some of the 68 companies included in this research. We need to note that, in this case, we used only three components in the non-linear part; our ICT support column data provided only basic information on the existence of the ICT support. Due to the confidentiality of company data, the names of companies are not disclosed.

Table 7. Resulting values for the selected companies.

Company	*Industry*	*NCE*	*ACF*	*AIDB*	*ICTS*	*Linear Part of CIOICTI*	*Non-Linear Part of CIOICTI*	*CIOICTI Value*
C_{46}	Prod.	0.214	0.194	0.000	0.000	6.121	0.000	**6.121**
C_{68}	Prod.	0.429	0.288	0.000	0.000	10.741	0.000	**10.741**
C_{66}	Prod.	0.064	0.200	1.000	0.000	18.957	0.511	**19.468**
C_{39}	Prod.	0.105	0.194	1.000	1.000	34.478	0.812	**35.290**
C_{29}	Serv.	1.000	0.163	1.000	0.000	32.438	6.500	**38.938**
C_{30}	Prod.	0.059	0.275	1.000	0.000	20.014	0.652	**20.666**
C_{43}	ICT	1.000	0.125	1.000	0.000	31.875	5.000	**36.875**
C_{60}	Prod.	0.134	0.669	1.000	1.000	42.042	3.586	**45.628**
C_{67}	Serv.	1.000	0.656	1.000	0.000	39.844	26.250	**66.094**
C_{51}	Prod.	0.163	1.000	1.000	1.000	47.445	6.520	**53.965**
C_{36}	ICT	1.000	0.475	1.000	1.000	52.125	19.000	**71.125**
C_{40}	Comm.	1.000	1.000	1.000	1.000	60.000	40.000	**100.000**

Generally, the CIOICTI shows low values in organisations where computers are rare or even not used, where core processes in the organisation are driven without th ICT or below capacity (for example, computers used as simple typewriters and calculators). In contrast, companies with an advanced level of ICT development, with the incorporated ERP systems application, active internet presence and electronic office collaboration achieved high values of the CIOICTI, representing the sound ICT development.

Further, we investigated the average level of ICT development concerning organisational size and industry sector. In the following Table 8, we present average values of the CIOICTI concerning the company size, according to the three EU criteria: number of employees, income and assets.

Table 8. Average values of CIOICTI with respect to the company size.

Aspect	Company Size	Average CIOICTI Value	Standard Deviation
Number of employees	*Small*	39.909	22.284
	Medium	48.089	20.691
	Large	48.527	23.624
Company income	*Small*	39.442	21.702
	Medium	44.890	16.849
	Large	62.607	24.780
Company assets	*Small*	38.435	22.221
	Medium	48.690	20.267
	Large	53.531	19.978

As expected, the results showed that, on average, small companies have the lowest level of ICT development, while large companies have the highest level of ICT development. In Table 9, we present results concerning the industry sector.

Table 9. Average values of the CIOICTI with respect to the industry sector.

Industry Sector	Average CIOICTI Value	Standard Deviation
Production	27.839	14.794
Commerce	45.686	21.811
ICT	59.710	19.792
Services	58.575	15.215

As expected, the production sector, as labour-intensive, has achieved the lowest level of ICT development. On the other hand, the ICT and Services as ICT-intensive industries achieved the highest average level of ICT development according to the CIOICTI

The proposed composite formula enables a decision-maker to control the influence of the components of changing the weighting scheme. This was not the case with the old CIICT index formula used as a basis for developing the proposed indicator. Absence of the explicit factor weighting made the old formula dependent on the influence of two components that created more than 60% of the influence on the composite value. In the following Table 10, we present summary statistics for the CIOICTI formula and the components' average contribution to the composite value.

Table 10. Summary statistics for the CIOICTI.

CIOICTI Component	NCE	ACBF	AIDB	ICTS	Linear Part of the CIOICTI	Non-Linear Part of the CIOICTI	CIOICTI Value
Min value	0.04	0.00	0.00	0.00	2.14	0.00	2.14
Max value	1.00	1.00	1.00	1.00	60.00	40.00	100.00
Average value	0.52	0.41	0.87	0.54	35.03	8.42	43.44
Standard deviation	0.35	0.24	0.34	0.50	14.38	9.43	22.02
Average contribution to the CIICT value	21.77%	16.54%	31.30%	15.87%	85.49%	14.51%	

The proposed composite indicator has good scalar traits unlike the old index formula with the ordinal measurement character that calculated substantial values on the higher end of the spectrum [32]. It is bounded between min and max values of 0 and 100, with the more balanced influence of the components. The average composite value in our data sample is 43.44, very close to the sample median of 42.90, which indicates non-skewness [57] and normality in the distribution of indicator values [58]. If we look at the distribution of the CIOICTI values, presented in Table 11 and Figure 1, we notice that except the thicker tail on the lower end of the spectrum (left tail), the distribution of the CIOICTI values much more resemble the normal distribution.

Table 11. The distribution of the CIOICTI values on the observed data sample.

Indicator Range	Number of Companies
$0 \leq$ CIOICTI ≤ 10	6
$10 <$ CIOICTI ≤ 20	3
$20 <$ CIOICTI ≤ 30	10
$30 <$ CIOICTI ≤ 40	12
$40 <$ CIOICTI ≤ 50	12
$50 <$ CIOICTI ≤ 60	12
$60 <$ CIOICTI ≤ 70	5
$70 <$ CIOICTI ≤ 80	4
$80 <$ CIOICTI ≤ 90	2
$90 <$ CIOICTI ≤ 100	2

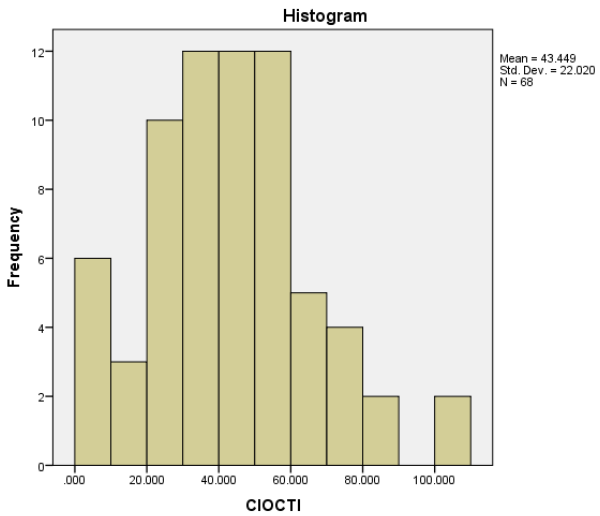

Figure 1. Histogram of the CIOICTI distribution.

Further, there are exactly 34 results (50% of the sample) below the CIOICTI mean value of 43.45 and 34 results above it. Moreover, there are 46 results (67.65% of the sample) falling into an interval of plus/minus one standard deviation around the mean value of the CIICT, and 66 results (97.06% of the sample) falling into plus/minus two standard deviations around the mean value. All these resulting statistics are strong indications that the resulting values are distributed normally. For this reason, we tested the normality of the obtained results.

4.3. Testing Normality of the Resulting Distribution

To test normality, we used Shapiro–Wilk and Kolmogorov–Smirnov tests. The Kolmogorov–Smirnov test is usually used for large samples, and the Shapiro–Wilk test is for small samples, so we present resulting statistics for both tests. We tested the following hypothesis:

Hypothesis 0. *"Distribution of CIOICTI values on the observed sample is normal"*.

Hypothesis 1. *"Distribution of CIOICTI values on the observed sample is not normal"*.

The resulting test statistics are shown in Table 12.

Table 12. Tests of Normality.

	Kolmogorov–Smirnov [a]			Shapiro–Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
CIOICTI	0.064	68	0.200 *	0.983	68	0.457

* this is a lower bound of the true significance. [a] Lilliefors Significance Correction.

In both the Shapiro–Wilk and Kolmogorov–Smirnov tests, resulting *p*-values are greater than 0.05; we can reject the alternative (**H1**) and accept the null hypothesis (**H0**) that the observed CIOICTI values have a normal distribution. The following Figure 2 represents a Normal Q-Q plot, the graphical method to test for the normality of data. If the data are normally distributed, the data points will be close to the diagonal line. As we can see from the figure, the data are normally distributed.

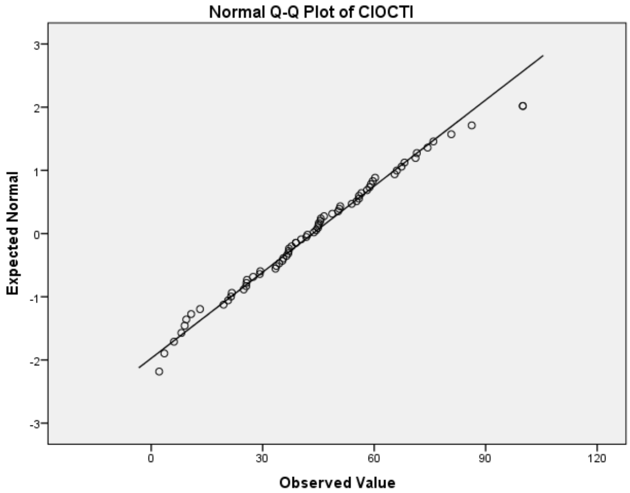

Figure 2. Normal Q-Q plot of CIOICTI.

The acceptance of the null hypothesis is connected to the diffusion of innovation theory [59] with successive groups of adopters of the new technology. By that theory, adopters (e.g., ICT adopters) are typically distributed and grouped into innovators, early adopters, early majority, late majority and laggards. Since the development of ICT infrastructure is closely related to the adoption of ICT, and we can expect cumulatively higher results with more prolonged usage, it seems logical that the development of ICT infrastructure is also normally distributed, reflecting the theory of Rogers. The normality of the CIOICTI distribution is proven which confirms the validity of the proposed indicator as a tool for measuring ICT development in a business organisation. We suspect that the innovators and early adopters are the companies with the highest level of the CIOICTI, while the laggards are the ones with the lowest level of ICT development. Still, this assumption remains to be tested in some future work.

4.4. Limitations

The study's main limitation is that data were gathered in the Southeast Europe (SEE) region, considered a frontier/developing region. Furthermore, the proposed form of the CIOICTI does not cover economic development background—a company from a developed country should have better ICT infrastructure than a company from an undeveloped country. However, if those two companies have equal CIOICTI values, it would indicate similar ICT development even though it probably means that the first one is a leader in its country and the second one is lagging behind the competition. Hence, benchmarking the economic background is necessary to interpret the results reasonably. Moreover, the proposed CIOICTI cannot rate relative differences in the ICT development among companies in different industry sectors. For example, the CIOICTI value of 30 in bioinformatics would probably mean heavy undevelopment, while in the timber industry companies, it would be a high level of ICT infrastructure development.

Another limitation of the proposed CIOICTI formula is the weighting scheme. The current weighting scheme is expert-based, defined taking into account the authors' experience and predefined objectives. Expert-based weights are subjective and could lead to underweighting or overweighting some factors. This should be addressed in the future work using some quantitative method such as AHP or a similar method. This would make composite index more objective in its nature. Further, the CIOICTI can be a valuable tool for managing ICT development in non-ICT business organisations in the SEE region. However, it may need to be reweighted in order to be used for measuring ICT development in a highly developed economy. For example, the NCE ("Number of Computers per Employee") component may be obsolete in ICT-based companies in developed economies, which is considered an inevitable prerequisite for starting and operating a business. Inclusion of ICT devices such as tablet computers and smartphones in everyday business activities can also be subjective, but its utilisation is at least formalised and limited by weighting and range.

5. Conclusions

The development of ICT infrastructure (hardware, software and humanware) is a significant factor for corporate success. The significance of this issue comes from the fact that if we cannot measure ICT development, we cannot manage it efficiently. This article proposes an improved composite indicator based on the one utilised in practical consulting and research [31,32,42]. We realised that it was much more oriented toward infrastructure than the adoption during its practical usage. This created a need to develop the proposed Composite Indicator of Organisational ICT infrastructure to measure its level in a business organisation as a composite tool consisting of several indicators aggregated using the weighted sums.

The proposed CIOICTI is a scaled on a [0, 100] value interval. The factor weighting enables a decision-maker to control the influence of the components according to their importance or problem specificity. Besides the linear aggregation of the components, the composite indicator also includes one non-linear part (geometric aggregation) introduced to favor companies that have integrated both hardware and software aspects of ICT infrastructure. The proposed indicator form is tested on the data set consisting of 68 companies. Further, the resulting distribution is successfully tested for normality, indicating that ICT development in an organisation can be related to the diffusion of innovation theory, which seems logical since ICT adoption and ICT development are hardly separable processes.

The limitations of our research are in the mathematical background focus and results. The general style and background of the article are not based on the advanced research in the field of Mathematics, but this paper is aimed at researching "innovative mathematical universe of instruments and techniques based on the statistical indices method", following the call to "improve statistics or financial mathematics methodologies, instruments, techniques, etc., generating optimal solutions for complex economic and social phenomena, reflecting the importance of indices' method in applied Statistics and Economics." Since there are currently no widely accepted and/or known results with rigorous mathematical foundations to compare our findings in organisational ICT application against, we believe that this would indeed be an encouragement for further research in this area. Limitations of our mathematical apparatus should inspire future research with advanced methods—e.g., fuzzy aggregation of indicator components which will further improve the indicator, respecting its basic business and organisational nature and functionality.

Further, limitations of our results impose the need to be verified from different research perspectives. Future research can use this indicator to measure the ICT development level explicitly and compare it with a wide range of other organisational traits, such as productivity, efficiency, leadership styles, and organisational culture, or include it in an elaborated model of some organisational phenomenon. Such usage of the proposed CIOICTI could discover emerging trends among companies from different industries to establish referent values.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Analysed data available online: https://1drv.ms/x/s!AgVfsXCLP7-ngcITVCvIvgemTfykEQ?e=WdVGYn. Last accessed on 20 July 2022.

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Abbreviations

ICT	Information and communication technologies
CIOICTI	Composite Indicator of the Organisational Information and Communication Technologies Infrastructure
CIICT	Composite Index of ICT Adoption
NCE	Number of Computers per Employee
INC	Internal Network Coverage
ACBF	Average Coverage of Business Functions with ICT
AIDB	Average Integration of Database
ICTS	Information and communication technologies support

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