COMPARATIVE ANALYSIS OF MCDM METHODS FOR THE ASSESSMENT OF ICT DEVELOPMENT IN G7 COUNTRIES[1]

Kafkas University
Economics and Administrative Sciences Faculty
KAUJEASF
Vol. 13, Issue 25, 2022
ISSN: 1309 – 4289
E – ISSN: 2149-9136

Article Submission Date: 16.10.2021 *Accepted Date: 26.11.2021*

Nazlı ERSOY
Res. Asst. Dr.
Kilis 7 Aralık University
Faculty of Economics and Administrative Sciences,
Kilis, Turkey
ersoynazli3@gmail.com
ORCID ID: 0000-0003-0011-2216

ABSTRACT | Information and communication technology (ICT) enable information to be accessed and processed through all kinds of visual, audio, printed and written tools. This study aimed to evaluate the ICT development of G7 countries by using Multi Criteria Decision Making (MCDM) methods. Accordingly, the Entropy method was used to specify the criteria weights, and the Proximity Indexed Value (PIV), Range of Value (ROV), and the COmplex PRoportional ASsessment (COPRAS) methods were used to rank the alternatives. In the final stage, the rankings obtained by the Entropy based PIV, ROV, COPRAS methods were compared with the results obtained by the Level Based Weight Assessment (LBWA) based Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) method, and a comparative analysis was performed. Finally, it was determined that the criteria weights obtained by objective and subjective methods had different effects on the ranking results.

Keywords: *Objective weighting, MCDM, entropy*
JEL Codes: *C40, C01, D81*

Scope: *Business Administration*
Type: *Research*

DOI: 10.36543/kauiibfd.2022.003

Atıfta bulunmak için: Ersoy, N. (2022). Comparative analysis of MCDM methods for the assessment of ICT development in G7 countries. *KAÜİİBFD,* 13(25), 55-73.

[1] It has been declared that the relevant study complies with the ethical rules.

G7 ÜLKELERİNDE BİT GELİŞİMİNİN DEĞERLENDİRİLMESİ İÇİN ÇKKV YÖNTEMLERİNİN KARŞILAŞTIRMALI BİR ANALİZİ

Kafkas Üniversitesi
İktisadi ve İdari Bilimler Fakültesi
KAÜİİBFD
Cilt, 13, Sayı 25, 2022
ISSN: 1309 – 4289
E – ISSN: 2149-9136

Makale Gönderim Tarihi: 16.10.2021 *Yayına Kabul Tarihi: 26.11.2021*

Nazlı ERSOY
Arş. Gör. Dr.
Kilis 7 Aralık Üniversitesi
İktisadi ve İdari Bilimler Fakültesi,
Kilis, Türkiye
ersoynazli3@gmail.com
ORCID ID: 0000-0003-0011-2216

ÖZ | Bilgi ve iletişim teknolojileri (BİT), her türlü görsel, işitsel basılı ve yazılı araçlar aracılığıyla bilgiye ulaşılmasını, bilginin işlenmesini sağlamaktadır. Bu çalışmada, Çok Kriterli Karar Verme (ÇKKV) yöntemleri kullanılarak G7 ülkelerinin BİT gelişiminin değerlendirilmesi amaçlanmıştır. Bu doğrultuda, Entropy yöntemi kriterlerin ağırlıklarını belirlemek amacıyla kullanılmış, Yakınlık Endeksli Değer (PIV), Değer Aralığı (ROV), ve Karmaşık Oransal Değerlendirme (COPRAS) yöntemleri ise alternatifleri sıralamak için kullanılmıştır. Bu çalışmanın son aşamasında, Entropy temelli PIV, ROV, COPRAS yöntemleri ile elde edilen sıralamalar ile Seviye temelli ağırlık değerlendirme (LBWA) temelli Uzlaşma Çözümüne Göre Alternatiflerin Ölçülmesi ve Sıralanması (MARCOS) yöntemi ile elde edilen sonuçlar kullanılarak karşılaştırmalı bir analiz gerçekleştirilmiştir. Çalışma sonunda, objektif ve subjektif yöntemlerle elde edilen kriter ağırlıklarının sıralama sonuçları üzerinde farklı etkiye neden olduğu saptanmıştır.

Anahtar Kelimeler: *Objektif ağırlıklandırma, ÇKKV, entropi*
JEL Kodları*: C40, C01, D81*

Alan: *İşletme*
Türü: *Araştırma*

1. INTRODUCTION

Information and Communication Technology (ICT) is an aggregation of various technological equipment and resources used to communicate. It is also a tool for generating, distributing, collecting and managing information (Sarkar, 2012, p. 31). ICT has significant potential to promote development and realize economic growth. Today, ICT is a constituent of many activities such as the supply of government services, commerce, entertainment, education and health (Yousefi, 2011, p. 581).

The subject of ICT has been discussed in the literature under many different topics such as economy (Meng & Li, 2002), economic growth and energy consumption (Ishida, 2015), health (Mahmud et al. 2013), sustainable energy consumption (Yan et al. 2018), trade (Nath & Liu, 2017), staff development (McCarney, 2004), education (Sarkar, 2012).

The number of studies dealing with ICT using Multiple-criteria decision-making (MCDM) methods is quite limited. Merkevičius & Yadav (2019) analyzed the integration and use of ICT in virtual business using the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and Simple Additive Weighting (SAW) methods. The proposed model was suitable for the problem addressed. Chen & Chen (2015) assessed and proposed critical IC criteria to contribute to the information industry using Decision Making Trial and Evaluation Laboratory (DEMATEL) and the Analytic Network Process (ANP) methods. It was proven that the proposed model was suitable for the evaluation of intellectual capital for ICT. Torkayesh and Torkayesh (2021) evaluated the development of ICT in G7 countries using integrated MCDM approach. Subjective the Level Based Weight Assessment (LBWA) method was preferred to find the criteria weights, Measurement Alternatives and Ranking according to Compromise Solution (MARCOS) method was preferred to rank the alternatives. At the end of the study, USA ranked first in terms of ICT performance, while Italy came last.

In subjective methods, the criteria are weighted according to the preferences and judgments of the decision makers. In objective methods, weighting is done by using only decision matrix elements without the need for decision makers' decisions. In integrated methods, decision makers' decisions and decision matrix data are used together (Wang & Luo, 2010, p. 1). In objective weighting methods, criteria weights are determined by using mathematical models. The subjective judgments of the decision maker are not taken into account (Zoraghi et al., 2013, p. 3). In the literature, besides the studies using the subjective weighting techniques (Hossain & Thakur, 2020; Das et al. 2021;

Cheng et al. 2020), there are also studies using objective methods (Zavadskas & Podvezko, 2016; Keshavarz-Ghorabaee et al. 2021; Sałabun et al. 2020).

This study aimed to evaluate ICT development in G7 countries using MCDM approach. In this direction, Entropy based Proximity Indexed Value (PIV), Range of Value (ROV), and COmplex PRoportional ASsessment (COPRAS) methods were used to evaluate the ICT development of G7 countries. Contrary to the study of Torkayesh & Torkayesh (2021), in this study, objective methods were chosen for weighting the criteria to fill the gap in the literature. A five-stage evaluation process was followed. In the first stage the alternative and criterion set were determined. In the second stage, criterion weights were determined by Entropy. In the third stage, the PIV, ROV, COPRAS methods were used to evaluate the G7 countries. In the fourth stage, the rankings obtained by the PIV, ROV, COPRAS were compared with the results obtained by the MARCOS method and comparative analysis was performed.

The literature contribution and advantages of the proposed model are as follows:

- The rankings obtained by MCDM methods with different algorithms were compared.
- The effect of criterion weights obtained by objective and subjective weighting methods on the results was revealed.
- The proposed model in this study was used for the first time for the ICT development evaluation of G7 countries.

The remainder of this article is organized as follows. The methodology section, which includes the mathematical formulations and explanations of the methods used in the study, is included in Section 2. Section 3 includes the application part. In Section 4, the comparative analysis section, in which the results of different methods are compared, is presented. In the last part, the conclusion and evaluation part is presented.

2. METHODOLOGY

In this section, firstly, the mathematical formulations of the Entropy method (criteria weighting method) are given. Then, the mathematical formulations and explanations of the PIV, ROV, COPRAS methods are given.

2.1. Entropy Method

Entropy is an objective method used to determine the importance of criteria. The steps of the Improved Entropy method are as follows (Wang & Lee, 2009, p. 8982):

Step 1: The decision matrix elements are normalized using equation (1).

$$P_{ij} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (1)$$

P_{ij} represents the value of the normalized decision matrix elements.

m represents alternatives, x_{ij} represents standard value. x_{ij} must be greater than zero ($x_{ij}>0$).

Step 2: The Entropy value for each units is calculated using equation (2).

$$e_j = -k\sum_{i=1}^{n} P_{ij} InP_{ij} \ \forall_j \quad (2)$$

where

$k = (\ln(n))^{-1}$

n indicates the number of alternatives.

Step 3: The degree of differentiation of the criteria is found using equation (3).

$$d_j = 1 - e_j, \ \forall_j \quad (3)$$

d_j shows the degree of differentiation. The more the d_j is, the more significant the criterion jth is.

Step 4: The normalized weight values for each criterion are found using equation (4).

$$W_j = \frac{d_j}{\sum_{k=1}^{n} d_k} \forall_i \quad (4)$$

w_j shows the weight of criterion.

2.2. PIV Method

This method was introduced by Mufazzal and Muzakkir (2018) to prevent the rank reversal phenomenon and has a simple calculation procedure.

The steps of the PIV method are as follows (Mufazzal & Muzakkir, 2018, p. 430-431).

Step 1: Decision matrix is created

The decision matrix is formed by determining the alternatives and the criteria.

Step 2: Decision matrix elements are normalized

Decision matrix elements are normalized using the equation (5).

$$r_i = \frac{x_i}{\sqrt{\sum_{i=1}^{m} x_i^2}} \tag{5}$$

r_i represents the value of the ith alternative.

Step 3: The weighted normalized decision matrix is determined

A weighted normalized decision matrix is formed using equation (6).

$$v_i = w_j * r_i \tag{6}$$

Step 4: Weighted proximity index (WPI) is calculated

The WPI is calculated to determine the closeness of alternatives to the best available solution. The deviation from the best value is measured by considering the benefit and cost-oriented criteria using equations (7) and (8).

$$u_i = v_{\max} - v_i \tag{7}$$

$$u_i = v_i - v_{\min} \tag{8}$$

Step 5: The total proximity value is determined

The total proximity value is calculated for each alternative using equation (9).

$$d_i = \sum_{j=1}^{n} u_j \tag{9}$$

Step 6: The alternatives are ranked

The alternative with the lowest d_j value takes the first place.

2.3. ROV Method

This method offers a simple calculation procedure to the decision-makers. The steps of the ROV method are as follows (Madić & Radovanović, 2015, p. 198-199).

Step 1: Decision matrix is created

A decision matrix is created that includes alternatives in rows and criteria in columns.

Step 2: Decision matrix elements are normalized.

Utility-side criteria and cost-side criteria are normalized using equation (10) and equation (11), respectively.

$$\bar{x}_{ij} = \frac{x_{ij} - x_{ij}^{\min}}{x_{ij}^{\max} - x_{ij}^{\min}} \tag{10}$$

$$\bar{x}_{ij} = \frac{x_{ij}^{\max} - x_{ij}}{x_{ij}^{\max} - x_{ij}^{\min}} \tag{11}$$

Step 3: The utility functions (best and worst) are calculated

In the last step, separate utility functions are created for the criteria. Utility functions (u_i^+, u_i^-) for benefit and cost criteria are presented in equations (12) and (13), respectively.

$$Max: u_i^+ = \sum_{j=1}^{n} \bar{x}_{ij}.w_j \tag{12}$$

$$Min: u_i^- = \sum_{j=1}^{n} \bar{x}_{ij}.w_j \tag{13}$$

w_j shows the criterion weights. Weights must necessarily meet the following two conditions:

$$\sum_{j=1}^{n} w_j = 1 \tag{14}$$

$$w_j \geq 0$$

If $u_i^- > u_i^+$ the alternative i can be said to be better than the *i* alternative, regardless of the total score.

$$u_i = \frac{u_i^- + u_i^+}{2} \tag{15}$$

The alternative with the highest u_i value takes the first place.

2.4. COPRAS Method

In the COPRAS method, the cost criterion is minimized while the benefit criterion is maximized. The steps of the COPRAS method can be summarized as follows (Das et al., 2012, p. 237; Chatterjee et al., 2011, p. 853):

Step 1: Decision matrix is created

The creation of the decision matrix constitutes the first step.

Step 2: Decision matrix is normalized

The decision matrix elements are normalized using equation (16).

$$x_{ij}^{*} = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \ (\mathrm{j} = 1,2,...,\mathrm{n}) \tag{16}$$

n shows criteria.

Step 3: Generating Weighted Normalized Decision Matrix (WNDM)

A WNDM is created using equation 17,

$$D^{'} = \left[d_{ij} \right]_{mxn} = x_{ij}^{*}.\mathrm{w}_{j} \tag{17}$$

$D^{'}$ indicates weighted decision matrix. W_j indicates criteria weights; x_{ij}^{*} shows the normalized value of the alternative i. on the basis of criteria j.

Step 4: Calculation of the beneficial and cost criteria

In this step, the criteria are characterized as useful (maximizing) and useless (minimizing). In the WNDM, first the useful criteria and then the useless criteria are calculated using equations 18 and 19.

$$S_{i+} = \sum_{j=1}^{k} d_{ij} \quad j = 1,2,...,k \qquad \text{useful criterion} \tag{18}$$

$$S_{i-} = \sum_{j=k+1}^{n} d_{ij} \quad j = k+1, k+2, ..., n \ \text{useless criterion} \tag{19}$$

Step 5: Calculation of Relative Significance Values **(Q_i)**

The relative significance value (Q_i) for alternatives is calculated using equation (20). The alternative with the highest relative importance is placed first.

$$Q_i = S_{i+} + \frac{\sum_{i=1}^{m} S_{i-}}{S_{i-} \sum_{i}^{m} \frac{1}{S_{i-}}} \quad (20)$$

Step 6: Calculation of Relative Significance Values

The highest relative importance value is found using equation (21).

$$Q_{\max} = \max\left(Q_i\right) \forall i = 1,2,...,m \quad (21)$$

Step 7: Calculation of Performance Index (P_i) Values for Alternatives

Performance index (P_i) values are calculated using equation (22).

$$P_i = \frac{Q_i}{Q_{\max}}.100\% \quad (22)$$

The alternative with 100 P_i is the best. Performance index values are ranked from largest to smallest.

3. APPLICATION

Based on the suggestions in Torkayesh and Torkayesh (2021)'s study, the same data set was used and criterion weights were determined by objective method. The development of G7 countries in ICT was evaluated according to various criteria. The criterion weights were specified using the Entropy method, which is an objective method. The PIV, ROV, COPRAS methods were used to rank the alternatives. The proposed framework is presented in Fig. 1.

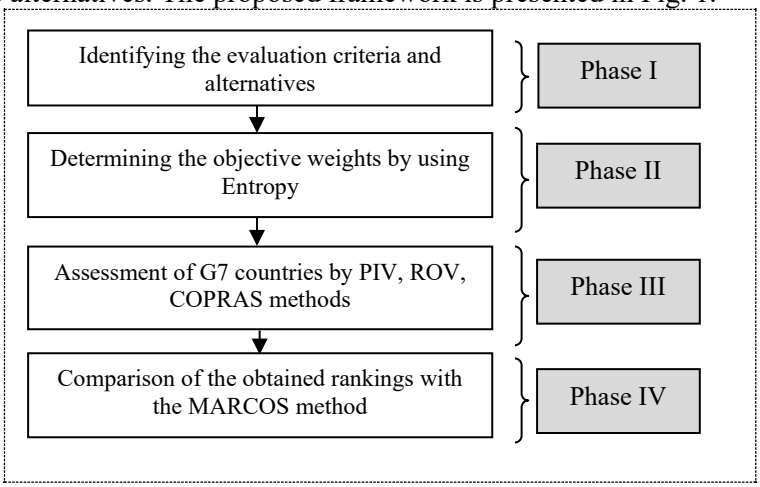

Figure 1: The Proposed Model of the Study
Source: Created by the author.

In all MCDM methods, the first step begins with the constitution of the decision matrix. In the second phase, the Entropy method was preferred to designate the weights of the criteria. This method has been preferred because it allows an objective evaluation, away from the subjective judgments of decision makers. In the third stage, the PIV, ROV and COPRAS methods were preferred in order to rank the alternatives. The PIV, ROV and COPRAS methods, which offer a simple calculation procedure, are preferred because they have never been used in a similar problem. In the fourth stage, the rankings obtained by the PIV, ROV, COPRAS methods were compared with the MARCOS method in to compare them with the study of Torkayesh & Torkayesh (2021). The model used in this study was chosen because it has not been tested for ICT evaluation before. In addition, objective methods, which are analyzed using only the decision matrix, were chosen. Methods that reflect the evaluations and subjective opinions of the decision makers (The Analytic Hierarchy Process (AHP), Step-Wise Weight Assessment Ratio Analysis (SWARA), etc.) and some fuzzy methods were not used in this study for the subjective evaluations not to have negative effects on the decision process.

3.1. Determination of Alternatives and Criteria

The alternatives are the seven countries in Table 2. The criterion sets are presented in Table 1.

Table 1: Indicators

Indicator	Unit	Definition	Reference
"Access to computer from home (I1)"	"% of all household"	Number of households with at least one working PC in their home.	OECD (2021a)
"ICT employment (I2)"	"% of business sector employment"	The people working in the ICT sector.	OECD (2021b)
"ICT goods exports (I3)"	"Million USD"	"ICT goods exports is based on the World Customs Organisation's Harmonised System (HS) which defines ICT products (including ICT goods)".	OECD (2021c)
"ICT investment (I4)"	%	"ICT investment is defined as the acquisition of equipment and computer software that is used in production for more than one year".	OECD (2021d)
"ICT value added (I5)"	"% of value added"	"CT added value is the difference between the gross output and intermediate consumption of the ICT sector".	OECD (2021e)
"Internet access (I6)"	"% of all household"	"Internet access is defined as the percentage of households who reported that they had access to the Internet".	OECD (2021f)

Source: Torkayesh and Torkayesh, 2021, p. 4.

3.2. Valuation of Criteria Stage (ENTROPY Method)

In all MCDM methods, the analysis begins with the constitution of the decision matrix. The decision matrix where the columns represent the criteria and the rows represent the alternatives (G7 countries) is presented in Table 2.

Table 2: Decision Matrix

Country	I1	I2	I3	I4	I5	I6
Canada	85.60	2.60	10,249	17.01	5.10	83.90
France	84.12	3.33	22,606	16.33	5.10	90.17
Germany	92.86	3.94	61,850	12.69	5.13	94.82
Italy	72.50	3.15	9,339	11.02	4.94	95.84
Japan	74.00	4.73	72,781	13.53	8.07	67.10
UK	91.66	4.26	20,080	23.76	7.36	85.17
USA	72.03	3.79	138,651	32.13	7.10	77.97

Source: Torkayesh and Torkayesh, 2021, p. 4.

In the first step, the decision matrix (Table 2) was normalized using equation (1). All the results are presented in Table 3.

Table 3: Normalized Decision Matrix

Country	I1	I2	I3	I4	I5	I6
Canada	0.149	0.101	0.031	0.135	0.119	0.141
France	0.147	0.129	0.067	0.129	0.119	0.152
Germany	0.162	0.153	0.184	0.100	0.120	0.159
Italy	0.127	0.122	0.028	0.087	0.115	0.161
Japan	0.129	0.183	0.217	0.107	0.189	0.113
UK	0.160	0.165	0.060	0.188	0.172	0.143
USA	0.126	0.147	0.413	0.254	0.166	0.131

Using the normalized decision matrix elements, Entropy measurements for each criterion were calculated using equation (2). Differentiation measures of criteria values were specified using equation (3). In the last step, the criteria weights were determined using equation (4). All the results are presented in Table 4.

Table 4: e_j, d_j Values and Criteria Weights (w_j)

	I1	I2	I3	I4	I5	I6
e_j	0.997	0.992	0.804	0.966	0.990	0.997
d_j	0.003	0.008	0.196	0.035	0.010	0.003
w_j	0.010	0.033	0.768	0.135	0.041	0.013

3.3. Ranking of Alternatives with PIV Method

In the first stage, the decision matrix (Table 2) was normalized using equation 5 (Table 5). A weighted normalized decision matrix was created using equation 6 (Table 6). The weighted proximity index is calculated using equations (7) and (8), and the total proximity value was calculated using equation 9 (Table 7).

Table 5: Normalized Decision Matrix

Country	I1	I2	I3	I4	I5	I6
Canada	0.393	0.262	0.060	0.332	0.309	0.371
France	0.387	0.336	0.132	0.319	0.309	0.399
Germany	0.427	0.398	0.360	0.248	0.311	0.419
Italy	0.333	0.318	0.054	0.215	0.299	0.424
Japan	0.340	0.477	0.424	0.264	0.489	0.297
UK	0.421	0.430	0.117	0.464	0.446	0.377
USA	0.331	0.383	0.808	0.628	0.430	0.345

Table 6: Weighted Normalized Matrix

Country	I1	I2	I3	I4	I5	I6
Canada	0.004	0.009	0.046	0.045	0.013	0.005
France	0.004	0.011	0.101	0.043	0.013	0.005
Germany	0.004	0.013	0.277	0.034	0.013	0.005
Italy	0.003	0.011	0.042	0.029	0.012	0.005
Japan	0.004	0.016	0.326	0.036	0.020	0.004
UK	0.004	0.014	0.09	0.063	0.018	0.005
USA	0.003	0.013	0.62	0.085	0.018	0.004

Table 7: The Weighted Proximity Index and Total Proximity Value (TPV)

Country	I1	I2	I3	I4	I5	I6	TPV	Rank
Canada	0.0004	0.007	0.575	0.04	0.007	0.0007	0.63	6
France	0.0004	0.005	0.519	0.042	0.007	0.0003	0.574	5
Germany	0	0.003	0.344	0.051	0.007	0.0007	0.405	3
Italy	0.001	0.005	0.579	0.056	0.008	0	0.649	7
Japan	0.001	0	0.295	0.049	0	0.0016	0.346	2
UK	0.0001	0.002	0.531	0.022	0.002	0.0006	0.557	4
USA	0.0001	0.003	0	0	0.002	0.001	0.008	1

3.4. Ranking of Alternatives with ROV Method

As a first step, the decision matrix is normalized using equation 10 (Table 8). The utility functions (best and worst) are calculated using equations 12 and 13 and alternatives are ranked according to their performance score (Table 9).

Table 8: Normalized Decision Matrix

Country	I1	I2	I3	I4	I5	I6
Canada	0.6515	0	0.007	0.2838	0.0511	0.585
France	0.5804	0.3427	0.1026	0.2515	0.0511	0.803
Germany	1	0.6291	0.4061	0.0791	0.0607	0.965
Italy	0.0226	0.2582	0	0	0	1
Japan	0.0946	1	0.4906	0.1189	1	0
UK	0.9424	0.7793	0.0831	0.6035	0.7732	0.629
USA	0	0.5587	1	1	0.6901	0.378

Table 9: Utility Functions and Ranking of the Alternatives

Country	I1	I2	I3	I4	I5	I6	u_i^+	u_i	Rank
Canada	0.007	0	0.005	0.038	0.002	0.007	0.0599	0.03	6
France	0.006	0.011	0.079	0.034	0.002	0.010	0.1424	0.0712	5
Germany	0.010	0.021	0.312	0.011	0.003	0.012	0.3684	0.1842	3
Italy	0.0002	0.009	0	0	0	0.013	0.0214	0.0107	7
Japan	0.001	0.033	0.377	0.016	0.041	0	0.4677	0.2338	2
UK	0.010	0.026	0.064	0.082	0.031	0.008	0.2203	0.1102	4
USA	0	0.019	0.768	0.135	0.028	0.005	0.9546	0.4773	1

3.5. Ranking of Alternatives with COPRAS Method

As a first step, the decision matrix elements are normalized using equation 16 (Table 10). A weighted normalized matrix is created using equation 17. Useful and useless criteria are created using equations 18 and 19. The relative importance values are calculated using equation 20 and the highest relative importance value is calculated using equation 21. All the results are presented in Table 11.

Table 10: Normalized Decision Matrix

Country	I1	I2	I3	I4	I5	I6
Canada	0.1494	0.1008	0.0310	0.1345	0.1190	0.1410
France	0.1469	0.1291	0.0670	0.1291	0.1190	0.1516
Germany	0.1621	0.1527	0.1840	0.1003	0.1200	0.1594
Italy	0.1266	0.1221	0.0280	0.0871	0.1150	0.1611
Japan	0.1292	0.1833	0.2170	0.1070	0.1890	0.1128
UK	0.1600	0.1651	0.0600	0.1879	0.1720	0.1432
USA	0.1258	0.1469	0.4130	0.2541	0.1660	0.1310

Table 11: Weighted Normalized Matrix and Ranking of the Alternatives

Country	I1	I2	I3	I4	I5	I6	∑	Qi	Rank
Canada	0.002	0.003	0.024	0.018	0.005	0.002	0.053	14.51	6
France	0.002	0.004	0.052	0.018	0.005	0.002	0.082	22.32	5
Germany	0.002	0.005	0.142	0.014	0.005	0.002	0.169	46.07	3
Italy	0.001	0.004	0.021	0.012	0.005	0.002	0.045	12.35	7
Japan	0.001	0.006	0.167	0.015	0.008	0.001	0.198	53.94	2
UK	0.002	0.006	0.046	0.025	0.007	0.002	0.087	23.83	4
USA	0.001	0.005	0.317	0.034	0.007	0.002	0.366	100	1

4. COMPARATIVE ANALYSIS

In this section, the effectiveness and advantages of the proposed ENTROPY-PIV-ROV-COPRAS model are demonstrated through comparison with the MARCOS method. Accordingly, the ranking results obtained by the MARCOS method are consistent with the results of other methods. Also, the results obtained by the four methods are the same. There is no difference. All the results obtained are presented in Table 12.

Table 12: Ranking Results under Different Scenarios

	Entropy based							
	PIV		ROV		COPRAS		MARCOS	
	d_i	Rank	u_i	Rank	Q_i	Rank	$f(K_i)$	Rank
Canada	0.6300	6	0.0300	6	14.5115	6	0.1888	6
France	0.5738	5	0.0712	5	22.3206	5	0.2586	5
Germany	0.405	3	0.1842	3	46.0742	3	0.4623	3
Italy	0.6485	7	0.0107	7	12.3502	7	0.1622	7
Japan	0.3464	2	0.2338	2	53.9362	2	0.5393	2
UK	0.5567	4	0.1102	4	23.8316	4	0.2932	4
USA	0.0075	1	0.4773	1	100	1	0.9631	1

Table 13: Ranking Results of LBWA Based MARCOS Model

	LBWA based MARCOS	
Country	$f(K_i)$	Rank
Canada	0.467	6
France	0.518	5
Germany	0.593	4
Italy	0.457	7
Japan	0.651	2
UK	0.634	3
USA	0.774	1

The ranking results obtained by the LBWA-based MARCOS method used in the study of Torkayesh & Torkayesh (2021) are presented in Table 13. Accordingly, USA took the first place in terms of ICT development performance, while Italy took the last place. The same problem was solved with Entropy based PIV, ROV, COPRAS, MARCOS methods in this study and the results are presented in Table 12. Accordingly, all rankings obtained by Entropy based PIV, ROV, COPRAS, MARCOS methods are the same.

Table 14: Final Results

	Entropy based				LBWA based
	PIV	ROV	COPRAS	MARCOS	MARCOS
	Rank	Rank	Rank	Rank	Rank
Canada	6	6	6	6	6
France	5	5	5	5	5
Germany	3	3	3	3	4
Italy	7	7	7	7	7
Japan	2	2	2	2	2
UK	4	4	4	4	3
USA	1	1	1	1	1

According to Table 14, the rankings of countries other than Germany and UK did not change. The rankings were not exactly the same, but showed slight deviations. The results in Table 14 actually show the different effects of objective and subjective methods on rankings.

The contributions of this study to the literature are as follows:

- The results obtained with objective and subjective criteria weighting methods were compared.
- Advantages and disadvantages of MCDM techniques with different algorithms have been utilized. The results obtained by different methods were compared.
- The rankings obtained with the different MCDM methods used were largely the same, and the results were found to be reliable.
- It has been determined that the rankings obtained by objective and subjective weighting techniques are not exactly the same.

In many studies in the literature (Štirbanović et al. 2019; Aldalou & Perçin, 2020), it has been determined that there are differences between the ranking results obtained by different MCDM methods. It is thought that the reason for the existing deviations is the differences in the algorithms of the MCDM methods. However, in this study, the rankings obtained by MCDM methods with different algorithms are the same. The fact that a large data set was not used in this study could be the reason for this situation. In this study, the results obtained with the objective and subjective criteria weighting method were compared.

5. CONCLUSION AND EVALUATION

In this study, the problem addressed in the study of Torkayesh and Torkayesh (2021) was handled with different MCDM methods based on the suggestions of the authors and the results were tested. In this direction, Entropy based PIV, ROV, COPRAS methods were used to evaluate the ICT development of G7 countries. Contrary to the study of Torkayesh and Torkayesh (2021), the objective method was chosen instead of the subjective method in order to weight the criteria in this study. A five-stage evaluation process was followed in the study. After the alternative and criterion set were determined, in the second stage, criterion weights were determined by Entropy, an objective method. In the third stage, PIV, ROV, COPRAS methods were used to evaluate the G7 countries. In the fourth stage, the rankings obtained by PIV, ROV, COPRAS were compared with the results obtained by Marcos method and comparative analysis was performed.

With this study;

- It has been determined that the criterion weights have an effect on the ranking results. It has been determined that the rankings obtained by the objective and subjective weighting methods are different from each other.
- MCDM methods with different algorithms can cause different sorting results. In this study, it was determined that the rankings obtained by PIV, ROV, COPRAS and MARCOS methods were the same.
- A comparison was made between MCDM methods with different algorithms and weighting methods in different categories.

Finally, it was determined that the ranking obtained with the LBWA-MARCOS model in the study of Torkayesh and Torkayesh (2021) and the rankings obtained with the Entropy-PIV-ROV-COPRAS-MARCOS model in this study were different from each other. This shows that the criteria weights have an effect on the ranking results. In future studies, integrated criterion weighting methods can be used and the results obtained can be compared.

6. CONFLICT OF INTEREST STATEMENT

There is no conflict of interest between the authors. (Single Author)

7. AUTHOR CONTRIBUTIONS

NE: The idea;
NE: Design;
NE: Collection and / or processing of resources;
NE: Empirical Analysis and / or interpretation;
NE: Literature search;

NE: Writer.

8. FUNDING ACKNOWLEDGEMENTS

This research received no specific grant from any funding agency.

9. ETHICS COMMITTEE STATEMENT AND INTELLECTUAL PROPERTY COPYRIGHTS

Ethics committee principles were followed in the study. There has been no situation requiring permission within the framework of intellectual property and copyrights.

10. REFERENCES

Aldalou, E., & Perçin, S. (2020). Application of integrated fuzzy MCDM approach for financial performance evaluation of Turkish technology sector. *International Journal of Procurement Management*, *13(1),* 1-23.

Chatterjee, P., Athawale, V. M., & Chakraborty, S. (2011). Materials selection using complex proportional assessment and evaluation of mixed data methods. *Materials and Design*, *32*, 851-860.

Chen, J. K., & Chen, I. S. (2015). The assessment of intellectual capital for the information and communication technology industry in Taiwan applying a hybrid MCDM model. *European J. of International Management, 9(1)*, 88–107.

Cheng, L. H., Cao, D. Q., & Guo, H. M. (2020). Analysis of coal mine occupational disease hazard evaluation index based on AHP-DEMATEL. *Archives of Environmental & Occupational Health*, 1-13.

Das, D., Datta, A., Kumar, P., Kazancoglu, Y., & Ram, M. (2021). Building supply chain resilience in the era of COVID-19: An AHP-DEMATEL approach. *Operations Management Research*, 1-19.

Das, M. C., Sarkar, B., & Ray, S. (2012). A framework to measure relative performance of Indian technical institutions using integrated fuzzy AHP and COPRAS methodology. *Socio-Economic Planning Sciences*, 46, 230-241.

Hossain, M. K., & Thakur, V. (2020). Benchmarking health-care supply chain by implementing Industry 4.0: a fuzzy-AHP-DEMATEL approach. *Benchmarking: An International Journal, 28(2)*, 556-581.

Ishida, H. (2015). The effect of ICT development on economic growth and energy consumption in Japan. *Telematics and Informatics*, *32(1)*, 79-88.

Keshavarz-Ghorabaee, M., Amiri, M., Zavadskas, E. K., Turskis, Z., & Antucheviciene, J. (2021). Determination of objective weights using a new method based on the removal effects of criteria (MEREC). *Symmetry, 13(4)*, 1-20.

Madić, M., & Radovanović, M. (2015). Ranking of some most commonly used non-traditional machining processes using ROV and CRITIC methods. *UPB Scientific bulletin, Series D: Mechanical Engineering, 77(2)*, 193-204.

Mahmud, A. J., Olander, E., Eriksén, S., & Haglund, B. J. (2013). Health communication in primary health care-A case study of ICT development for health promotion. *BMC medical informatics and decision making*, *13(1)*, 1-15.

McCarney, J. (2004). Effective models of staff development in ICT. *European Journal of Teacher Education*, *27(1)*, 61-72.

Meng, Q., & Li, M. (2002). New economy and ICT development in China. *Information economics and policy*, *14(2)*, 275-295.

Merkevičius, J., & Yadav, R. (2019). "Evaluation of ICT usages in virtual business by applying MCDM methods". *22nd Conference for Young Researchers" Economics and Management*, Vilnius, Lithuania.

Mufazzal, S., & Muzakkir, S. M. (2018). A new multi-criterion decision making (MCDM) method based on proximity ındexed value for minimizing rank reversals. *Computers & Industrial Engineering*, 119, 427-438.

Nath, H. K., & Liu, L. (2017). Information and communications technology (ICT) and services trade. *Information Economics and Policy*, 41, 81-87.

OECD, Access to computer from home (Indicator), 2021a, "https://data.oecd.org/ict/access-to-computers-from-home.htm" (Accessed on 06 October 2021).

OECD, ICT employment (Indicator), 2021b, "https://data.oecd.org/ict/ict-employment.htm" (Accessed on 06 October 2021).

OECD, ICT goods exports (Indicator), 2021c, "https://data.oecd.org/ict/ict-goods-exports.htm" (Accessed on 06 October 2021).

OECD, ICT investment (Indicator), 2021d, "https://data.oecd.org/ict/ict-investment.htm" (Accessed on 06 October 2021).

OECD, ICT value added (Indicator), 2021e, "https://data.oecd.org/ict/ict-value-added.htm" (Accessed on 06 October 2021).

OECD, Internet Access (Indicator), 2021f, "https://data.oecd.org/ict/internet-access.htm" (Accessed on 06 October 2021).

Sałabun, W.; W, Atróbski, J., & Shekhovtsov, A. (2020). Are MCDA methods benchmarkable? A comparative study of TOPSIS, VIKOR, COPRAS, and PROMETHEE II Methods. *Symmetry*, 12, 1-56.

Sarkar, S. (2012). The role of information and communication technology (ICT) in higher education for the 21st century. *Science*, *1(1)*, 30-41.

Štirbanović, Z., Stanujkić, D., Miljanović, I., & Milanović, D. (2019). Application of MCDM Methods for Flotation Machine Selection. *Minerals Engineering*, *137*, 140-146.

Torkayesh, A. E., & Torkayesh, S. E. (2021). Evaluation of information and communication technology development in G7 countries: An integrated MCDM approach. *Technology in Society*, *66*, 1-9.

Wang, T. C., & Lee, H. D. (2009). Developing a fuzzy TOPSIS approach based on subjective weights and objective weights. *Expert systems with applications*, *36(5),* 8980-8985.

Wang, Y. M., & Luo, Y. (2010). Integration of correlations with standard deviations for determining attribute weights in multiple attribute decision making. *Mathematical and Computer ModellingVolume, 51(1–2),* 1–12.

Yan, Z., Shi, R., & Yang, Z. (2018). ICT development and sustainable energy consumption: A perspective of energy productivity. *Sustainability*, *10(7),* 1-15.

Yousefi, A. (2011). The impact of information and communication technology on economic growth: Evidence from developed and developing countries. *Economics of Innovation and New Technology*, *20(6),* 581-596.

Zavadskas, E. K., & Podvezko, V. (2016). Integrated Determination of Objective Criteria Weights in MCDM. *International Journal of Information Technology & Decision Making*, 1–17.

Zoraghi, N., Amiri, M., Talebi, G., & Zowghi, M. (2013). A fuzzy MCDM model with objective and subjective weights for evaluating service quality in hotel industries. *Journal of Industrial Engineering International, 9(1),* 1-13.