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LINEAR ORDERING OF CITIES IN THE SMART CITY CONCEPT

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Purpose: Linear ordering is an important issue for evaluating multi-attribute objects. The issue of assessing cities in the context of their rating in the light of the smart city concept is a linear programming issue. The primary purpose of the article is to report the results of linear ordering obtained based on different methods and to present comparative analyses.
Design/methodology/approach: The data presented in the article are based on EUROSTAT. It refers to indicators characterising selected European capitals.
Findings: Based on the indicators selected from the database, the ranking of cities is determined based on the presented methods. The results obtained were used for benchmarking.
Originality/value: The most significant value of the work is the benchmarking that was carried out. The analysis proved that the TOPSIS method showed that the result obtained was similar to that obtained by SCI.

Keywords: Smart City, Eurostat, Hellwig method, TOPSIS method, linear ordering.

Category of the paper: Research paper.

1. Introduction

The issue of the Smart City concept is particularly important when we consider the fact that in 2030 more than 60% of the population will live in cities (United Nations, 2014). It can be said that Earth will become an urban planet. Cities must be adequately prepared for such a huge number of inhabitants. The Smart City concept is convenient to meet this challenge. The concept evolves with increasing data processing capabilities and the availability of all technologies using AI. The perception of the challenges facing the city is also changing. The city is being changed like a kind of organism that is evolving. The evolution of the city is aimed at such a redesign of the city that serves its inhabitants. We are already talking about Smart City 5.0 (Svítek, 2020).

Measurement and comparison are the goals all kinds of rankings should meet. Very often, the aspect of comparing obtained results is forgotten. Very often, the same result in the form of a ranking is presented. The ranking itself is not everything, it is important to delineate and indicate the ways of development. The Smart City concept has a hierarchical structure that is lost by imposing a concept of sustainability on it. The application of the concept of sustainable development results in the adoption of equal weights for each component. Many rankings are built, using different indicators. The data sources must be reliable (Ahvenniemi et al., 2017; Albino et al., 2015; Bosch et al., 2017a; Huovila et al., 2016; Stankovic et al., 2015; Lombardi, 2011; Tahir, 2016). Complexity means that there is no transparent assessment system. There are many concepts of a Smart City. The European Smart Cities Ranking uses six categories and 64 indicators, The Smart Cities Wheel considers six categories and 62 indicators, Bilbao Smart Cities Study uses six categories and 49 indicators. Smart City PROFILES consider just five categories and 21 indicators (Albino et al., 2015; Berrone et al., 2019; Bosch et al., 2017b.; Giffinger et al., 2007; Smart City PROFILES, 2013; Szczech-Pietkiewicz 2015; UCLG, 2012).

The categories, areas in which we perceive Smart Cities include: smart economy (ECO), intelligent population (PEO), smart management (GOV), intelligent mobility (MOB), intelligent environment (ENV), intelligent living conditions (LIV).

The construction of the Smart City rating is labour-intensive. It requires access to a database which often requires separate research. City rating is possible compared to other cities. Solutions should be sought to make the comparison possible without requiring additional financial resources, which can be achieved thanks to databases such as Eurostat. Eurostat is a reliable source of data. It has extensive databases of national and regional statistics. City related data are located in the Urban Audit database (Sojda et al., 2018).

2. Data and Methods

2.1. Data

Eurostat contains a database of cities. The data collected are from 1990 to 2019. The Urban Audit database contains 572 different indicators. Some indicators are objective. Subjective indicators are described on the Likert scale or by percentage share. The database contains 1,822 cities from 32 countries. Not all of them are described by the same number of indicators. The largest number of indicators is found for large cities and, above all, the capitals of countries. The study focused only on capitals that were selected using the data availability criterion.

For data related to the perception of cities by their citizens expressed on the Likert scale, the following solution was adopted. Weights (-2; -1; 0; 1; 2) are assigned to the response: (strongly disagree, very unsatisfied; somewhat disagree, unsatisfied; do not know/no answer, somewhat agree, rather satisfied; strongly agree, very satisfied). This allowed determining a synthetic answer to the question.

Variable values have been normalised (Kukuła, 1989, 2000; Sojda et al., 2020). The following tables list the indicators assigned to the relevant areas of the ranking.

Table 1.
Indicators in the ranking

INDIC	NAME	MD	SD
V01: ECO O1	Activity rate	1	S
V02: ECO O2	All companies	2	S
V03: ECO O3	Unemployment rate	0	D
V04: ECO S1	In this city it is easy to find a good job	0	S
V05: ECO S2	You have difficulty paying your bills at the end of the month	0	D
V06: ENV O1	Annual average concentration of NO2 (μg/m³)	0	D
V07: ENV O2	Annual average concentration of PM10 (μg/m³)	1	D
V08: ENV O3	Number of days particulate matter PM10 concentrations exceed 50 μg/m³	0	D
V09: ENV S1	The cleanliness in the city	0	S
V10: ENV S2	This city is committed to the fight against climate change (e.g.; reducing energy consumption in housing or promoting alternatives to transport by car)	0	S
V11: PEO O1	Employment (jobs) in professional, scientific and technical activities; administrative and support service activities (NACE Rev. 2, M and N)	5	S
V12: PEO O2	Median population age	3	D
V13: PEO O3	Proportion of population aged 25-64 qualified at level 5 to 8 ISCED, from 2014 onwards	2	S
V14: PEO S1	Foreigners who live in this city are well integrated	0	S
V15: PEO S2	Schools in the city	0	S
V16: LIV O1	Infant mortality rate (per 1000 live births)	0	D
V17: LIV O2	Number of deaths per year under 65 due to diseases of the circulatory or respiratory systems	2	D
V18: LIV O3	Number of murders and violent deaths	1	D
V19: LIV S1	Health care services offered by doctors and hospitals in this city	0	S
V20: LIV S2	You feel safe in this city	0	S
V21: MOB O1	Cost of a combined monthly ticket (all modes of public transport) for 5-10 km in the central zone - EUR	2	D
V22: MOB O2	Number of registered cars per 1,000 inhabitants	3	S
V23: MOB O3	Share of journeys to work by public transport (rail, metro, bus, tram) - %	8	S
V24: MOB S1	Means of transport primarily used to go to work/training place: public transport	0	S
V25: MOB S2	Public transport in the city, for example, bus, tram or metro	0	S

The factors were then transformed to match the desired higher values of the indicator. Most factors are de-stimulants (D). When the character changed, they became stimulants (S).

MD indicates how many data were missing for the variable. The SD column indicates whether the factor was a stimulant (S) or a de-stimulant (D).

Table 2.
Cities in the ranking

CAPITAL	MD	POPULATION
Vienna	3	1,766,746
Brussels	0	1,205,492
Sofia	0	1,238,438
Prague	2	1,324,277
Berlin	0	3,613,495
Copenhagen	1	559,440
Tallinn	0	430,805
Athens	2	664,046
Madrid	1	3,223,334
Paris	0	9,803,494
Helsinki	0	643,272
Budapest	1	1,749,734
Dublin	2	516,255
Rome	1	2,872,800
London	3	8,866,541
Vilnius	0	547,484
Luxembourg	2	115,227
Riga	0	632,479
Amsterdam	0	960,402
Oslo	1	623,966
Warsaw	2	1,735,442
Lisbon	1	507,220
Bucharest	4	2,131,034
Stockholm	0	949,761
Ljubljana	0	288,919
Bratislava	1	432,864
Zagreb	3	804,049

Fundamental statistical indicators for the transformed variables were examined.

Table 3.
Statistical parameters of indicators after standardisation

INDIC	Range	IQR	Quartile 1	Quartile 2	Quartile 3	Skewness	Kurtosis
V1	3.46	1.57	-0.85	0.08	0.72	-0.20	-0.97
V2	3.94	1.20	-0.62	-0.14	0.58	0.39	0.02
V3	3.93	1.33	-0.67	0.18	0.66	-0.61	-0.12
V4	3.72	1.33	-0.58	0.26	0.76	-0.79	-0.32
V5	4.11	1.39	-0.76	-0.08	0.63	0.70	0.42
V6	3.95	1.31	-0.71	0.22	0.60	-0.49	-0.17
V7	3.79	0.86	-0.29	0.12	0.57	-0.94	0.82
V8	3.96	1.07	-0.31	0.25	0.77	-1.64	2.65
V9	4.02	1.62	-0.86	0.19	0.76	-0.18	-0.66
V10	3.49	1.36	-0.63	0.09	0.73	-0.05	-0.88
V11	3.58	0.88	-0.67	-0.40	0.20	1.66	1.90
V12	3.56	0.99	-0.35	-0.06	0.64	-0.33	-0.34
V13	4.14	1.07	-0.36	0.09	0.71	-0.33	0.23
V14	4.53	1.25	-0.46	-0.07	0.79	-0.60	0.90
V15	3.18	1.81	-1.02	0.08	0.79	0.00	-1.30
V16	4.90	1.06	-0.42	0.14	0.64	-1.94	6.48
V17	4.57	0.42	0.08	0.38	0.49	-3.02	10.16
V18	2.45	2.11	-1.33	0.42	0.78	-0.51	-1.58

Cont. table 3.

V19	3.09	1.81	-0.90	-0.02	0.91	-0.16	-1.36
V20	3.57	1.40	-0.57	0.07	0.83	-0.71	-0.02
V21	3.23	1.28	-0.43	-0.08	0.85	-0.60	-0.45
V22	3.42	1.10	-0.72	-0.08	0.38	0.64	-0.28
V23	4.07	1.69	-1.10	0.06	0.59	0.81	1.30
V24	3.76	1.65	-0.84	0.04	0.81	0.11	-0.81
V25	4.99	0.85	-0.32	0.14	0.53	-0.91	2.27

The values of the statistical parameters indicate the differentiation between variables. No variable could unambiguously distort the results of the ranking. Variables can be considered as appropriately selected.

2.2. Methods

Let us assume that we want to evaluate m objects that are described by n variables. In this case, we analyse the cities described by indicators.

Hellwig linear ordering method

The Hellwig method has the concept of a pattern (Hellwig 1968, 1981). The pattern is also called a reference point.

It is assumed that the variables are stimulants. Higher variable values indicate the desired higher level of the phenomenon. If a variable is not a stimulant, the value of the variable is multiplied by -1.

Designation procedure

Stage 1 – standardisation. Very often variables are expressed in different units and have different order of magnitude, so variables are standardised. As a result of standardisation, variables have the following properties. The mean is zero, the standard deviation is one. The value range usually varies from -3 to 3. The variable is standardised according to the formula:

$$z_{ij} = \frac{x_{ij} - \bar{x}_j}{s_j} \tag{1}$$

where:

x_{ij}– observation of the j-th indicator, for the 1st object,

$\bar{x}_j$– the average value for j-th indicator,

s_j– standard deviation value for j-th indicator.

Stage 2 – specification of the coordinates of the standard. After you standardise variables, you can specify the coordinates of the pattern. All indicators are stimulants. The formula founds the value of the pattern:

$$z_{0j} = \max\{z_{ij}\} \tag{2}$$

Step 3 – determining the distance from the pattern. Euclidean distance is used to determine the distance of objects from the pattern.

$$d_{0i} = \sqrt{\sum_j (z_{0j} - z_{ij})^2} \tag{3}$$

Stage 4 – determining the value of an aggregate variable. To determine the value of an aggregate variable one needs to determine: the average distance from the standard (3), the standard deviation of the distance from the standard (4).

$$\bar{d}_0 = \sum_j d_{0i} \tag{4}$$

$$s_0 = \sqrt{\frac{1}{n}\sum_i (\bar{d}_0 - d_{0i})^2} \tag{5}$$

Based on the average and the deviation of the standard distance from the standard we determine the critical distance of the pattern according to the formula:

$$d_0 = \bar{d}_0 + 2s_0 \tag{6}$$

After determining a critical distance, we can calculate the value of the aggregate variable according to the formula.

$$q_{\mathrm{i}} = 1 - \frac{d_{0i}}{d_0} \tag{7}$$

Based on the aggregate value one can designate the best object - $\max\{q_{\mathrm{i}}\}$, and the worst object - $\min\{q_{\mathrm{i}}\}$.

TOPSIS method

The TOPSIS method is an extension of the Hellwig method (Hwang et al., 1918). This method uses two reference points. The first is a pattern that is analogous to the Hellwig pattern. The second is an anti-pattern.

Step 1 – designation of pattern and anti-pattern

$$z_{0j}^{+} = \max\{z_{ij}\} \tag{8}$$

$$z_{0j}^{-} = \min\{z_{ij}\} \tag{9}$$

Step 2 – determining the distance from patterns. Similarly, as in the Hellwig method, distances from each pattern are determined on the basis of formulas:

$$d_{0i}^{+} = \sqrt{\sum_j (z_{0j}^{+} - z_{ij})^2} \tag{10}$$

$$d_{0i}^{-} = \sqrt{\sum_j (z_{0j}^{-} - z_{ij})^2} \tag{11}$$

Step 3 – determining the value of the aggregate variable. To determine the value of the variable, it is necessary to know the distance value (10), (11).

$$q_{\mathrm{i}} = \frac{d_{0i}^{-}}{d_{0i}^{-} + d_{0i}^{+}} \tag{12}$$

Smart City Index

The larger the aggregate variable values, the better the object.

$$\mathrm{SCI} = \frac{\sum OI_i w_i}{\sum w_i} \tag{13}$$

for the area

$$OI_i = \frac{\sum I_{ij} v_{ij}}{\sum v_{ij}} \tag{14}$$

where:

I_{ij} – value of the j-th variable, a measure included in the i-th area,

v_{ij} – weight of the j-th variable, the measure included in the i-th area $\sum_j v_{ij} = 1$,

OI_i – index value for the i-th area,

w_i – the weight of the i-th area $\sum_i w_i = 1$,

all weights are non-negative.

The indicator includes the following relationships between areas and their measures. It was considered that for determining the SCI value each area would have the same weight. The SCI value is the arithmetic mean of the indexes from the areas.

3. Results and discussion

According to the methodology presented, the following ranking of cities was obtained.

Table 4.
Ranking results with comparison

CAPITAL	RANKING R:			VALUE V:			SCI VS HELLWIG	SCI VS TOPSIS
	SCI	HELWIG	TOPSIS	SCI	HELWIG	TOPSIS		
Helsinki	1	1	1	0.46	0.38	0.63	0	0
Oslo	2	2	2	0.45	0.38	0.63	0	0
Tallinn	3	4	3	0.42	0.37	0.62	-1	0
Stockholm	4	7	5	0.36	0.32	0.60	-3	-1
Vilnius	5	3	4	0.36	0.37	0.61	2	1
Amsterdam	6	5	7	0.32	0.34	0.60	1	-1
Prague	7	6	6	0.30	0.33	0.60	1	1

Cont. table 4.

Copenhagen	*8*	*10*	*8*	*0.22*	*0.27*	*0.57*	*-2*	*0*
Luxembourg	9	12	9	0.21	0.26	0.57	-3	0
London	10	9	10	0.12	0.27	0.57	1	0
Paris	11	8	11	0.10	0.30	0.56	3	0
Vienna	12	18	12	0.08	0.23	0.55	-6	0
Ljubljana	13	17	14	0.06	0.23	0.54	-4	-1
Dublin	14	16	13	0.04	0.23	0.55	-2	1
Berlin	15	14	16	-0.03	0.25	0.54	1	-1
Riga	16	11	15	-0.03	0.26	0.54	5	1
Budapest	17	15	17	-0.07	0.24	0.53	2	0
Brussels	18	13	19	-0.07	0.26	0.52	5	-1
Bratislava	19	19	18	-0.09	0.22	0.52	0	1
Sofia	20	22	21	-0.10	0.18	0.52	-2	-1
Warsaw	21	20	20	-0.13	0.22	0.52	1	1
Lisbon	22	21	22	-0.19	0.20	0.51	1	0
Madrid	23	23	23	-0.20	0.17	0.50	0	0
Zagreb	24	24	24	-0.26	0.17	0.49	0	0
Rome	25	25	25	-0.66	-0.02	0.41	0	0
Athens	26	26	26	-0.79	-0.05	0.40	0	0
Bucharest	27	27	27	-0.88	-0.06	0.37	0	0

In the light of the variables presented, Helsinki turned out to be the best city. Scandinavian capitals rank high. Smaller capitals also occupy high places. By comparing the results obtained, it can be concluded that the results obtained by TOPSIS are the closest to the SCI results.

Pearson's determined linear correlation coefficients indicate a strong linear relationship with the results obtained.

Table 5.
Pearson's determined linear correlation coefficients

	SCI:R	HELLWIG:R	TOPSIS:R	SCI:V	HELLWIG:V	TOPSIS:V
SCI:R	1.00					
HELLWIG:R	0.95	1.00				
TOPSIS:R	1.00	0.95	1.00			
SCI:V	-0.93	-0.90	-0.93	1.00		
HELLWIG:V	-0.88	-0.90	-0.88	0.98	1.00	
TOPSIS:V	-0.93	-0.91	-0.93	1.00	0.98	1.00

The table compares the results of the rankings and the meters based on which they were created. Strong linear correlation relationships can be noticed. Therefore, these measures can be used interchangeably. When comparing the rankings with rankings using SCI, we see that the most significant change is present with the Hellwig method. It takes into account only the distance from the positive pattern. The TOPSIS method changes apply to at most one position.

4. Conclusion

The measure of Hellwig's economic development as well as TOPSIS can be successfully used as linear ordering measures in the context of Smart City. Their advantage over SCI is that they can not only rank but also assess the distance. In the future it will be possible to try to construct a meter based on one of these two measures showing not only the ranking position. The advantage of these measures is that they take values in the range [0,1].

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